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BENTONITE MINING RELATED RECLAMATION PROBLEMS

in the Northwestern States

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MONTANA DEPARTMENT OF STATE LANDS

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BENTONITE MINING RELATED RECLAMATION PROBLEMS

in the Northwestern States

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PREPARED BY: D. HEMMER, S. JOHNSON AND RAY BECK

EDITED BY: P. CHENEY

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INTRODUCTION

This study was initiated by the Montana Department of State Lands, through funding from the Old West Regional Commission, in order to better understand the problems associated with bentonite mine reclamation, and then to recommend how such problems can be alleviated. Bentonite is a montmorillonite clay, of which there are two types used commercially: calcium, or nonswelling bentonite; and sodium, swelling, or Wyoming bentonite. A three-state area emcompassing South Dakota, Montana, and Wyoming contains 90 to 95 percent of the world's commercially minable deposits of Wyoming bentonite (Robert Baker, personal communication). Here thousands of acres of land have been disturbed by bentonite mining, and in fact, such disturbance is greater at the present time than that created by coal mining. Since much of this land was mined prior to the enactment of reclamation laws, it is doubtful that such land will be returned to a productive use. As a result of an increased demand for bentonite, many areas that once could not be profitably mined are now being disturbed.

In the past reclamation of land mined for bentonite has proven difficult; hence the more specific objectives of this study have been:

1. To determine the basic problems associated with bentonite reclamation: by surveying reclamation literature and determining what material might be applicable to bentonite mining reclamation; by identifying geologic bentonite deposits in the Region; and by analyzing selected test areas.
2. To select sites based on the above information and then to establish research plots on the sites for testing reclamation procedures and materials.

Bentonite has many uses: from a mud for oil-well drilling and a sealant of reservoirs, to a clarifier of wine and a binder in asprin. In fact, the Belle Fourche Daily Post (South Dakota, September 26, 1972) referred to bentonite as the clay of 1000 uses (Figure 1). The major uses include: a component of well-drilling mud, foundry moldings, and sealants, and a binder of taconite ore. Since the mid 1960's, the demand for bentonite to produce taconite-ore pellets has increased substantially.

The quality of bentonite varies from bed to bed, and to a certain extent, location within the bed. A bentonite area is first drilled on a grid to determine both the bed's extent and the depth of the overburden. Then, the grid spacing of the drilling is reduced or intensified in order to delineate those portions of the bed which are of acceptable quality and thickness. A mining company usually has contracts to supply bentonite for several uses, each of which has different quality specifications. The company thus must have on hand a number of grades to meet contract demands, which necessitates the opening of a number of pits in various beds and in various locations within a bed. This results in a hopscotch type of mining with several pits at various locations open at any one time.

The depth to which a company will mine bentonite depends on the grade and thickness of the bed. As a rule, no more than ten feet of overburden will be removed for each foot of bentonite; that is, the stripping ratio will not exceed 10:1. Normally pits are relatively small, not over 50 feet deep, and covering from three to ten acres. Pits are mined either in a cut-and-fill sequence or in a haphazard fashion, depending on bed quality, thickness, and overburden depth.

The Daily Post
Tuesday, September 26, 1972
Belle Fourche, S.D.

BENTONITE--THE CLAY OF 1000 USES

Bentonite has for many years been called "The Clay of 1000 Uses", and a list of the products in which the strange clay is involved indicates the number is not an excessive exaggeration.

Here are some of the products in which bentonite is used, either in processing of the products or in the item itself. This list is by no means complete, since new uses are being found periodically.

abrasive wheels
asphalt roads
arc-welding
building blocks
batteries
clay brick
clarifying agent (wine, vinegar, oil)
cold-water paints
cleansing agent
casein
dentifrices
degreasing (hides, wool)
dikes
electrolyte solution
floor emulsions
facial clay packs
fire brick
foundry sand
gypsum
golf green binder
horticultural sprays
insecticides
internally (X-rays)
irrigation ditches
lead pencils
leather treatment
magnesia
mortar
mining
nitro-starch explosives
porcelain
plaster
paste
phonograph records
paper
pipes
refining (fats, greases)
reservoir walls
seed disinfecting
sewer pipe
sizing agent (cord)
sewage treatment
shoe polish
tar varnishes
water colors
wall sealing agent
Zeolite water softeners
asbestos
auto-polish
beauty clays
bleaching agents
concrete
crayons
calcimines
crude oil
dynamite
dry cells
de-inking agent
detergents
enamels
fertilizer
fire extinguishers
filtration
germicides
glauconite cement
graphite crucibles
highways
insulators
insulation board
kerosene
lubricating oil
lacquers
masonary cement
magnesium
mechanic's soap
ointments
plastic
poles
printer's ink
paints
paperboard
rubbing stones
rubber
sheep & cattle dips
spark plugs
slag cement
stock feed
scouring soaps
stove polish
textile printing
waterproof concrete
wall board
well drilling (oil)
artificial stone
anticorrosive
bricklayers cement
briquets
blood albumen
cement tile
cork
cardboard
chicle
dye fixatives
dust preventive
dams
electrical insulation
fungicides
face cream
fire clay
fruit juices
glazes
glue
gelatinizing agent
hair treatment
indelible lead
insulation blocks
linoleum cement
laxatives
latex
matches
medicinal emulsions
metal polish
oil paints
pottery
posts
pastel colors
putty
plaster board
roofing paper
rosin preventive
rosin
rubber tire puncture preventative
stucco
sizing (cotton, yarn)
sticking agent (sprays)
special soaps
thread cutting compounds
valve-grinding compounds
wood dips
waterproof paper
water coagulant

Figure 1. BENTONITE--THE CLAY OF 1000 USES

BACKGROUND

HISTORY

According to the Belle Fourche Daily Post (September 26, 1972), the first claims were filed on bentonite in the Belle Fourche area in 1923, although the first processing plant was not begun until 1934. Today there are 10 processing plants in four major areas of active bentonite mining. These four areas are:

1) The Belle Fourche, South Dakota - Colony, Wyoming - Alzada, Montana area
2) The Upton, Wyoming area
3) The Kaycee, Casper, Wyoming area
4) The Lovell, Greybull, Tensleep, Wyoming - Warren, Montana area.

In addition, an area near Vananda, Montana was mined from 1947 to July of 1977, and another near Glasgow and Malta, Montana is in the early stages of development.

GEOLOGY

The geological history of bentonite has been briefly stated by Byrne & Farvolden (1959):

> Bentonite is generally regarded as a rock produced by the alteration of volcanic ash to clay minerals of the montmorillonite group. Initially the ash consisted of small glass shards, which had been ejected by volcanoes and subsequently carried considerable distances by high-altitude winds. In the western part of the Great Plains, this ash was deposited in many places in large bodies of water where it slowly settled to the bottom, forming a relatively thin bed of great lateral extent. Because of the instability of glass under the conditions, the glass shards were then altered to one of the minerals of the montmorillonite group. Each bentonite bed may represent ash produced by several volcanic eruptions. Although most of the large cretaceous bentonite deposits mined in the Western Great Plains area were formed in a marine environment, some bentonite beds of this area occur in non-marine sediments.

The major geologic formations containing commercial bentonite in the three-state region are:

1. the Belle Fourche Formation in the Belle Fourche - Colony - Alzada Area
2. the Pierre Formation in the Belle Fourche - Colony - Alzada area
3. the Mowry Formation in the Belle Fourche - Colony - Alzada area, the Kaycee - Casper area, and the Glasgow - Malta area
4. the Thermopolis Formation in the Lovell - Greybull - Warren area
5. the Frontier Formation in the Lovell - Greybull - Warren area
6. the Bearpaw Formation in the Glasgow - Malta area and in the Vananda area.

A number of other formations in the three-state region contain bentonite of substandard quality. Since these formations have not been mined they are not considered in this study (Figures 2a and 2b illustrate both the commercial and noncommercial formations).

SOILS

Bentonite mining areas are characterized by relatively large outcrops of bentonite, or bentonitic shales, on which there is no topsoil and little or no vegetation. (A rule of thumb heard in the bentonite industry is: "if it will grow weeds, it is not good bentonite.") Bentonite soils tend to be weakly developed with thin A horizons. Soil depth increases as the bentonite beds dip downward. Although soils vary from area to area and from formation to formation, three characteristics are common to all: sodicity, salinity, and clay texture.

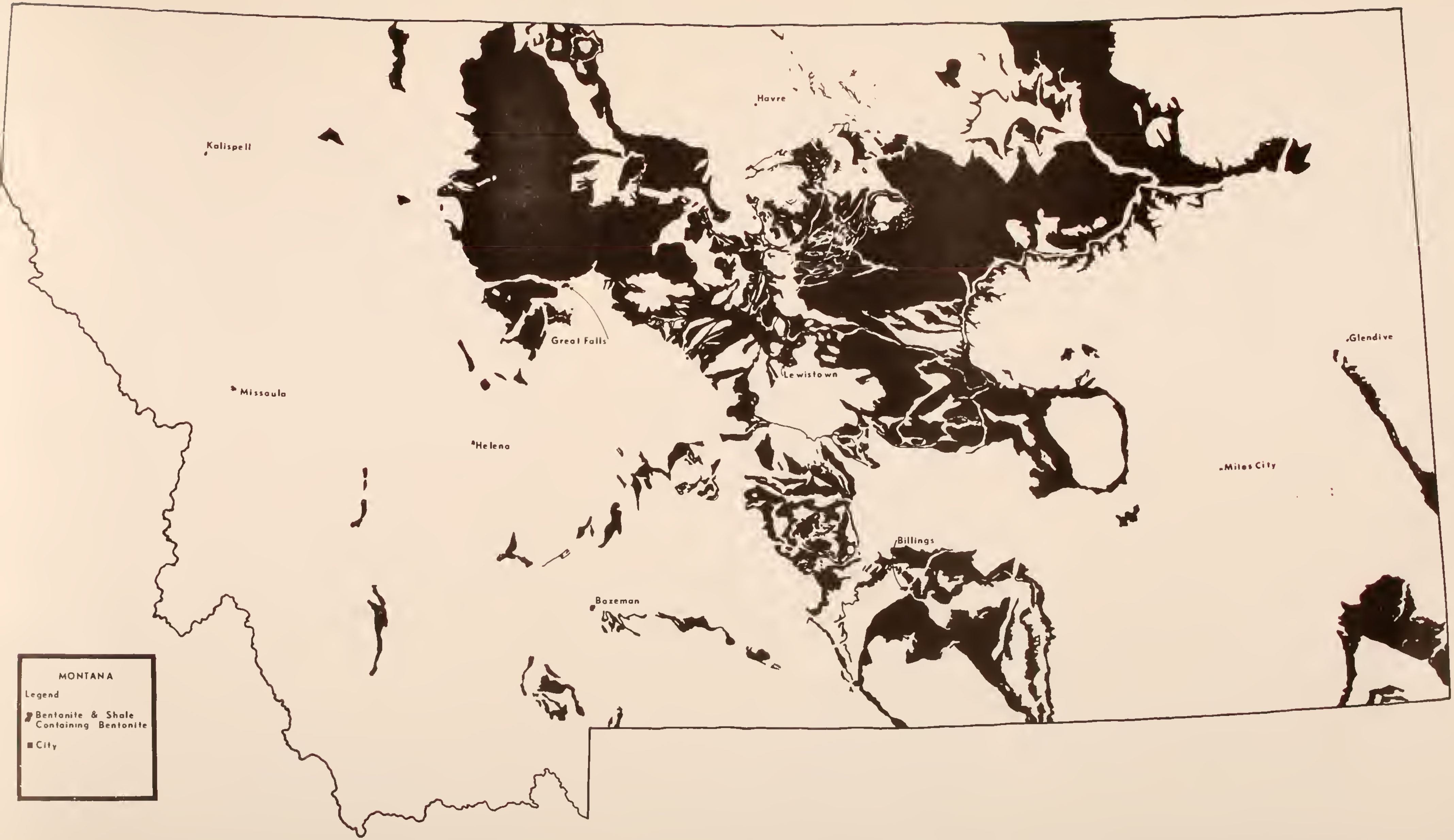


FIGURE 2B. BENTONITE DEPOSITS IN MONTANA.

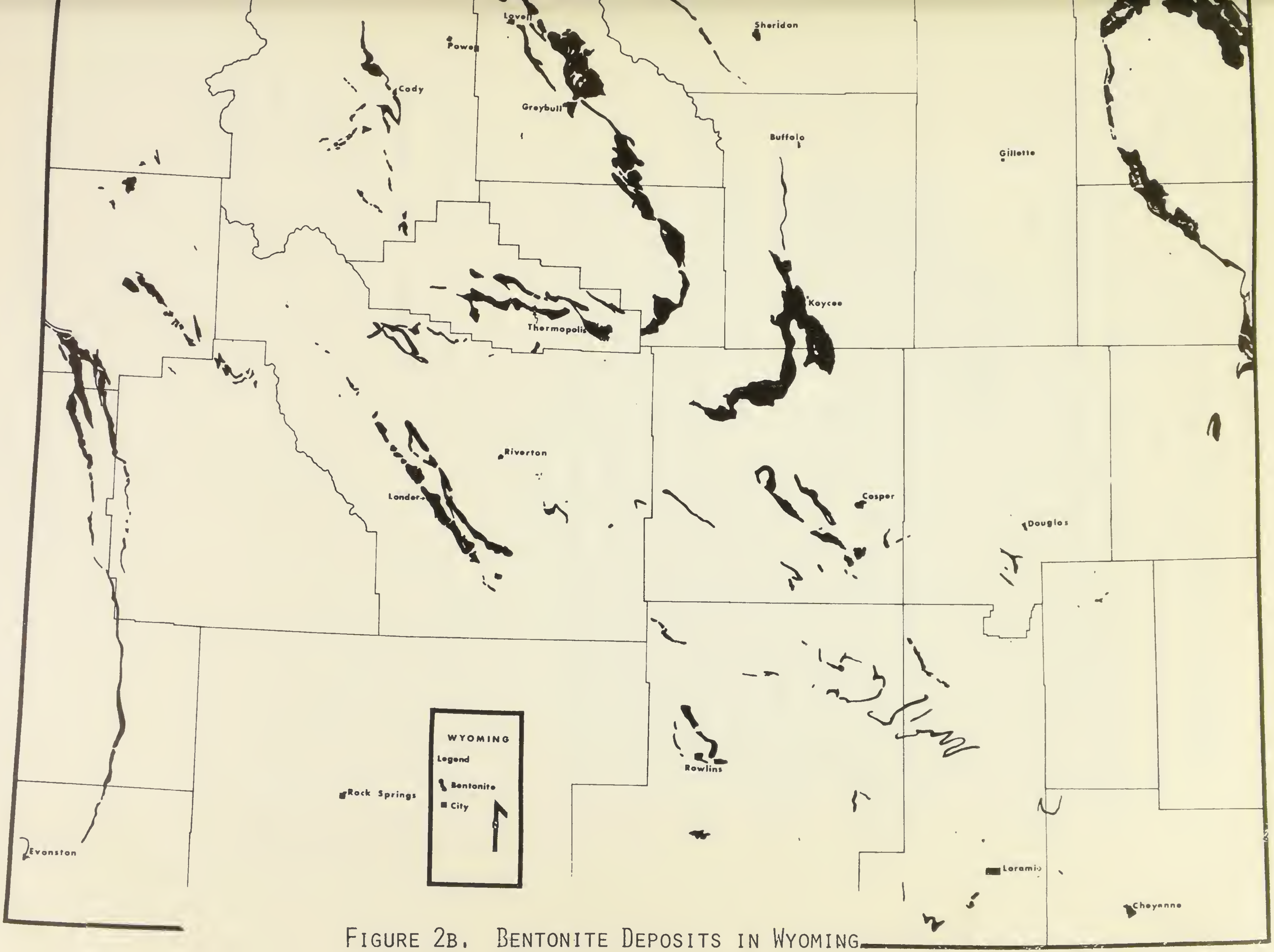


FIGURE 2B. BENTONITE DEPOSITS IN WYOMING

A sodic soil is one in which a large proportion of the cation exchange sites are occupied by sodium. Sodicity is expressed by the Sodium Adsorption Ratio (SAR), which formulates the ratio of sodium to calcium and magnesium on the exchange sites, and is calculated by the following formula:

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

In clays large amounts of sodium (high SAR) cause the clay particles to disperse, which in turn results in the soils becoming nearly impermeable and in reducing infiltration. One theory (DSL, 1977) suggests that roots may be penetrating primarily in soil cracks and fissures created by clay expansion and contraction. The SAR at which plant growth is inhibited is not precisely known; however, it is believed that at an SAR of 12 or greater plant establishment will be difficult. SAR's on the surface soils of the study sites ranged from 3.76 to infinity (the atomic absorbtion spectrophotometer could detect only sodium by water extraction in one sample from the Warren site).

Saline soils are ones which contain large amounts of salts as measured by electrical conductivity (E.C.). Salinity creates a harsh environment for plants by inhibiting water uptake. In saline soils plant water absorption is decreased because of a high solute concentration in the soil. Electrical conductivities above 4 indicate a soil which will require a saline adopted plant. E.C.'s on the study ranged from 0.9 to 39.7.

METHODS OF MINING

Draglines were used in early bentonite mining, and later, crawler tractors with scrapers were utilized. Today most of the mining is done with rubber-tired scrapers, although in areas of rough terrain, some operations use crawler tractors and scrapers. Mobility of heavy equipment is important in bentonite mining: since many pits, each of a different grade, must be open at a given time, the operator must be able to move equipment as dictated by demand.

In current mining methods, the scrapers strip the topsoil and place it on a filled pit or in a stockpile. The overburden is then removed and placed in adjoining pits and contoured into the surrounding environment. As a result of scraper mining, the overburden strata is reversed: the bentonite first exposed is actually a mixture of overburden and bentonite, commonly referred to as "cleanings." In the past these cleanings have been left on the surface of the overburden, although now they are placed at the toe of a highwall and covered with overburden. The uncovered bentonite is stockpiled and left to "field dry", a particularly effective method of drying in the Bighorn Basin because of its dry air conditions. Recently field drying has become more important because increasing fuel prices have made operation of kilns used for drying unfeasible. Once the bentonite is field dried, it is taken by truck or haul wagon to the plant for processing.

RECLAMATION

Until the late 1960's or early 1970's, little or no reclaiming of bentonite mining areas had been initiated. Spoils removed from the pits were simply left in heaps; the pits were left to form ponds, often resulting in boggy conditions and/or highwalls around the edges. The effect of this was to negate the ponds' potential as a watering site (Figure 3). In fact so many pits were left as ponds that there were far

more per unit area than were needed for stockwater. The last material to come out of the pit was cleanings, which were usually left on the surface, thus precluding revegetation. Old pits which, after periods of up to 50 years, have little or no vegetation can be seen northwest of Belle Fourche, South Dakota.

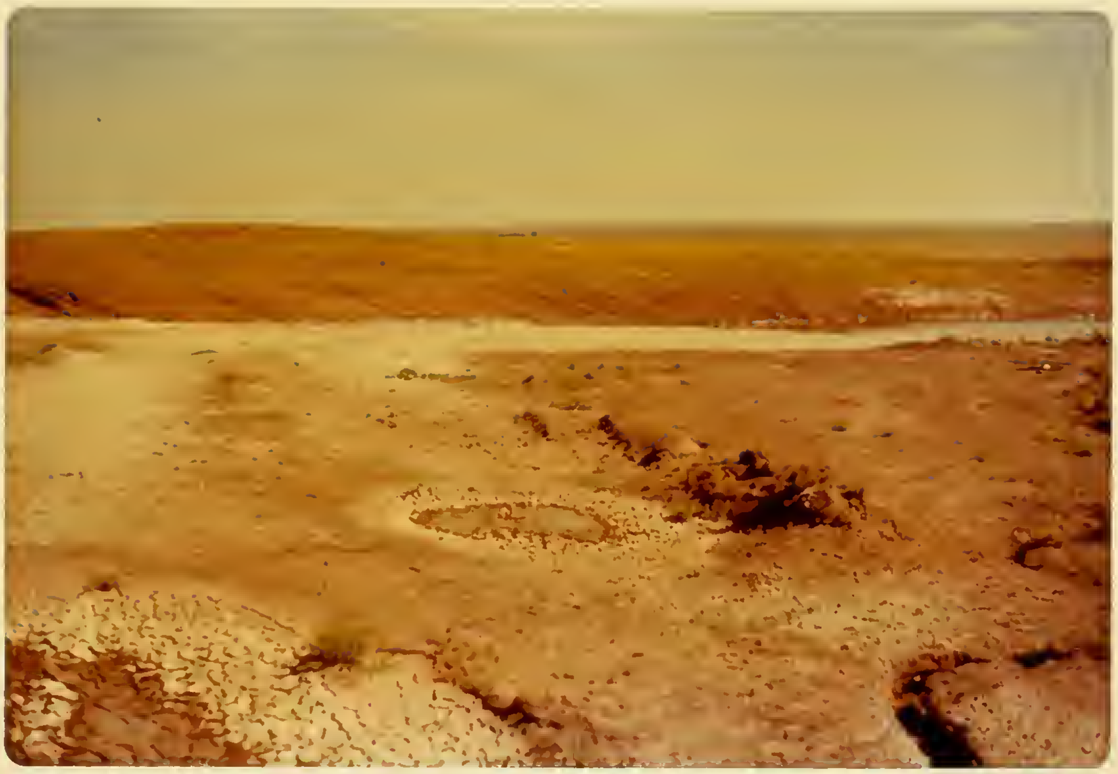


Figure 3. Unreclaimed bentonite pit.

With the beginning of the environmental movement, laws were passed which require reclamation of all land mined for bentonite. A review of reclamation to date, done as a part of this study, has revealed results ranging from success to total failure. Success has been related primarily to substrate and climate, and secondarily to the method of operation.

Care must be taken when evaluating reclamation. Obviously the same criteria cannot be applied to an area which before mining was a ponderosa pine grassland receiving 16 inches of rainfall and an area which was saltbush desert type receiving only 4 to 6 inches. The most successful reclamation was accomplished on areas of coarser shales in locales of

good precipitation. Evidently the coarseness of the shales overcomes, to an extent, the adverse effects of sodium. Of all the areas considered in the study, the Bighorn Basin has proven the most difficult to reclaim; this is so because soils are poorly developed, highly sodic and saline, and precipitation is low.

Problems brought about by the standard methods of mining and reclamation include: (1) topsoil contamination as a result of the salvaging of undesirable materials; (2) topsoil contamination as a result of the deposition of cleanings near the surface; (3) poor topsoil redistribution, leaving some areas with no topsoil; (4) creation of an impenetrable seed bed as a result of overcompaction of the regraded area; and (5) vegetation destruction as a result of livestock grazing. In some areas grazing had the greatest impact on reclamation. In fact reclamation is likely to fail if livestock are allowed to devastate the young succulent growth.

MATERIALS AND METHODS

In order to ascertain the extent to which bentonite mining and reclamation varied with area and operator, most of the active bentonite operations in the region were visited. The method of operation, reclamation practices, and an estimate of reclamation success were noted for each operation. At the same time soil samples were taken at random locations to measure variability within an individual mining area. Seven sites were selected which were felt to be representative (Figure 4). These sites are located:

1. ½ mile west of Colony, Wyoming
2. 5 miles west of Alzada, Montana
3. 5 miles northeast of Upton, Wyoming
4. 5 miles west of Vananda, Montana
5. 21 miles southwest of Glasgow, Montana

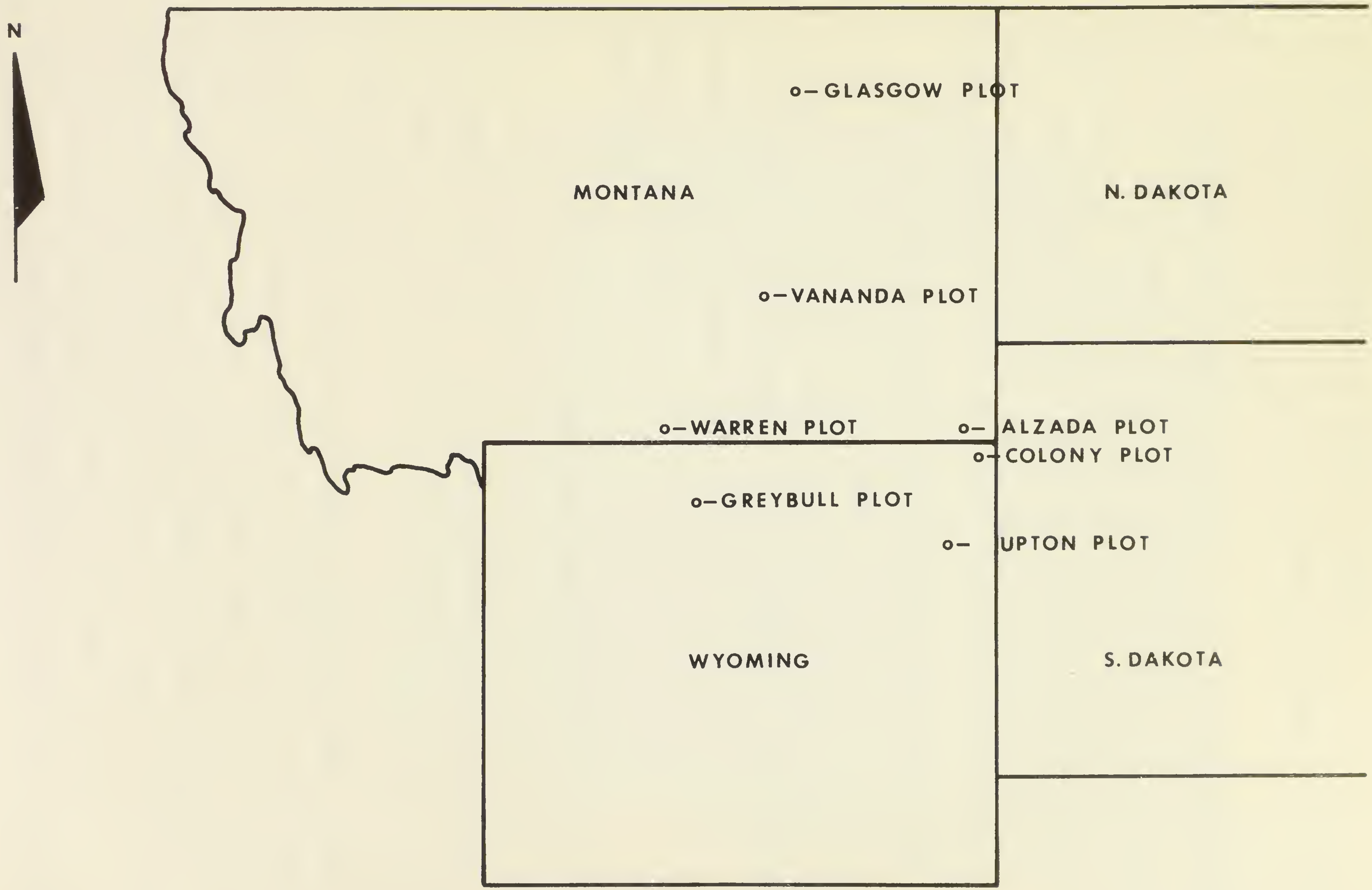


Figure 4. Test plot locations.

6. 10 miles northwest of Greybull, Wyoming
7. 3 miles northeast of Frannie, Wyoming (in Montana and referred to as the Warren Plot).

The Kaycee-Casper, Wyoming mining area was not selected because the U.S. Soil Conservation Service (S.C.S.) had previously established a test area there. Test plots were established on each site as a part of this study in order to utilize reclamation materials and techniques so that the maximum revegetation (given the climate and soil condition) could be achieved.

All sites had been mined in the same fashion, thus reducing any individual effect an operator could have had. Once mining had been completed, the sites were regraded and topsoiled to depths ranging from 0 to 4 inches. Suitable topsoil is a scarce commodity; thus research concerning depths in excess of that available after mining has no practical application.

PLOT DESIGN

The plots at all sites except Warren measured 145 feet by 120 feet with the long side perpendicular to the slope. Each plot was subdivided into subplots measuring 15 by 50 feet, arranged in two rows of eight. The subplots were further divided into 30 microplots measuring 5 feet by 5 feet (Figure 5).

The individual subplots were isolated with buffer zones: a 5-foot buffer was left between the fence and the seeded areas; a 2-foot buffer between the subplots; and a 10-foot buffer between the rows of subplots. Trenches were dug above the plot and between the rows of subplots so that surface run-off from adjacent areas did not affect a given subplot's moisture regime. All plots were fenced with 4-foot sheep fence in order to avoid stress from livestock grazing, although rabbits and deer could not be kept out.

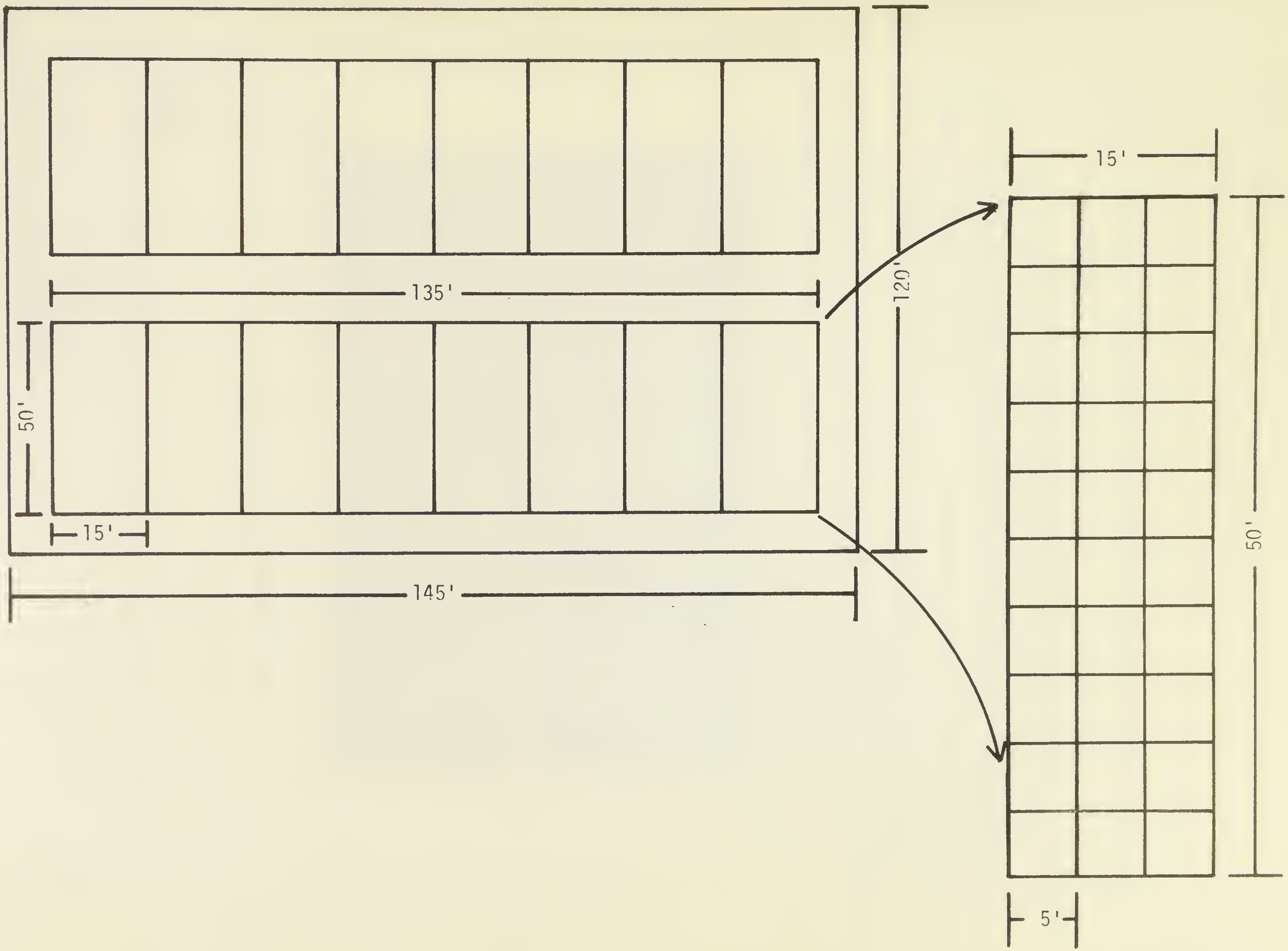


FIGURE 5. TEST PLOT DESIGN.

Warren Plot

While all other plots were seeded before the 1976 growing season, difficulties prevented the seeding of the Warren Plot until the fall. By that time new information necessitated altering the original plot design (Figure 6).

Thus, at Warren, 12 subplots measured 15 by 50 feet, with each divided into ten microplots measuring 5 by 15 feet. Seven species and three mixtures were seeded in the microplots. The two surface treatments and the control used on the other plots mentioned above were retained. A sandy material, limestone fines, was added to two subplots in order to overcome the poor physical condition of the soil (Figure 7).

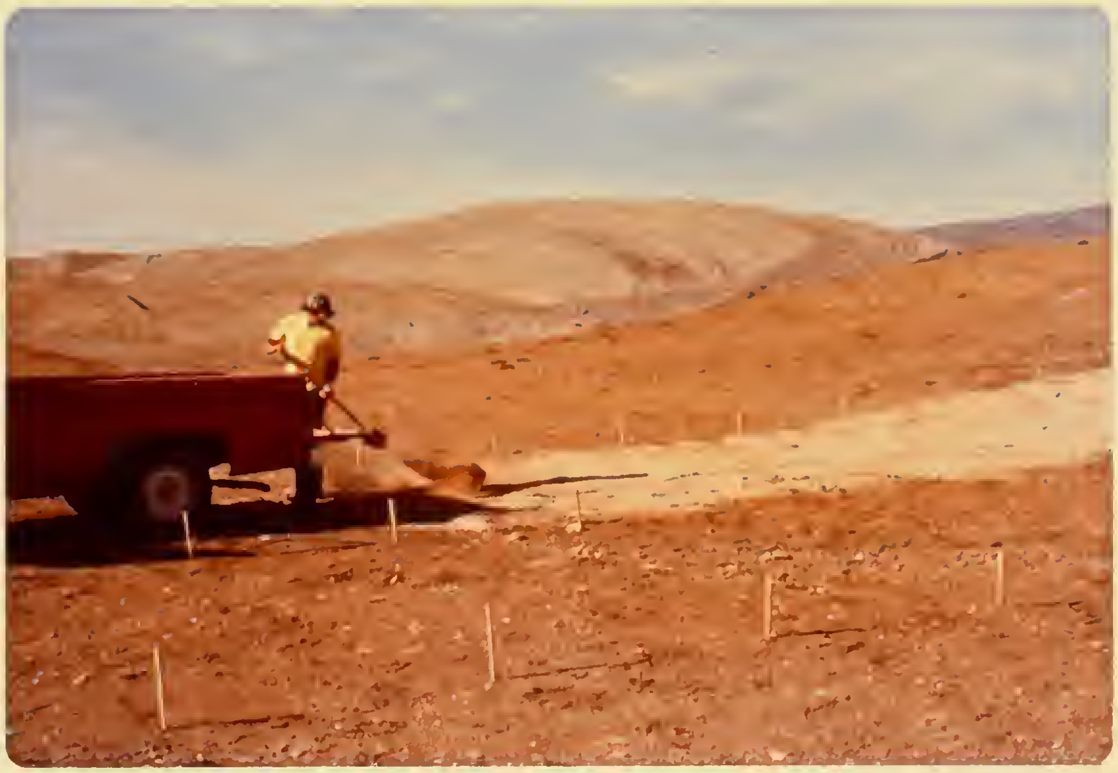
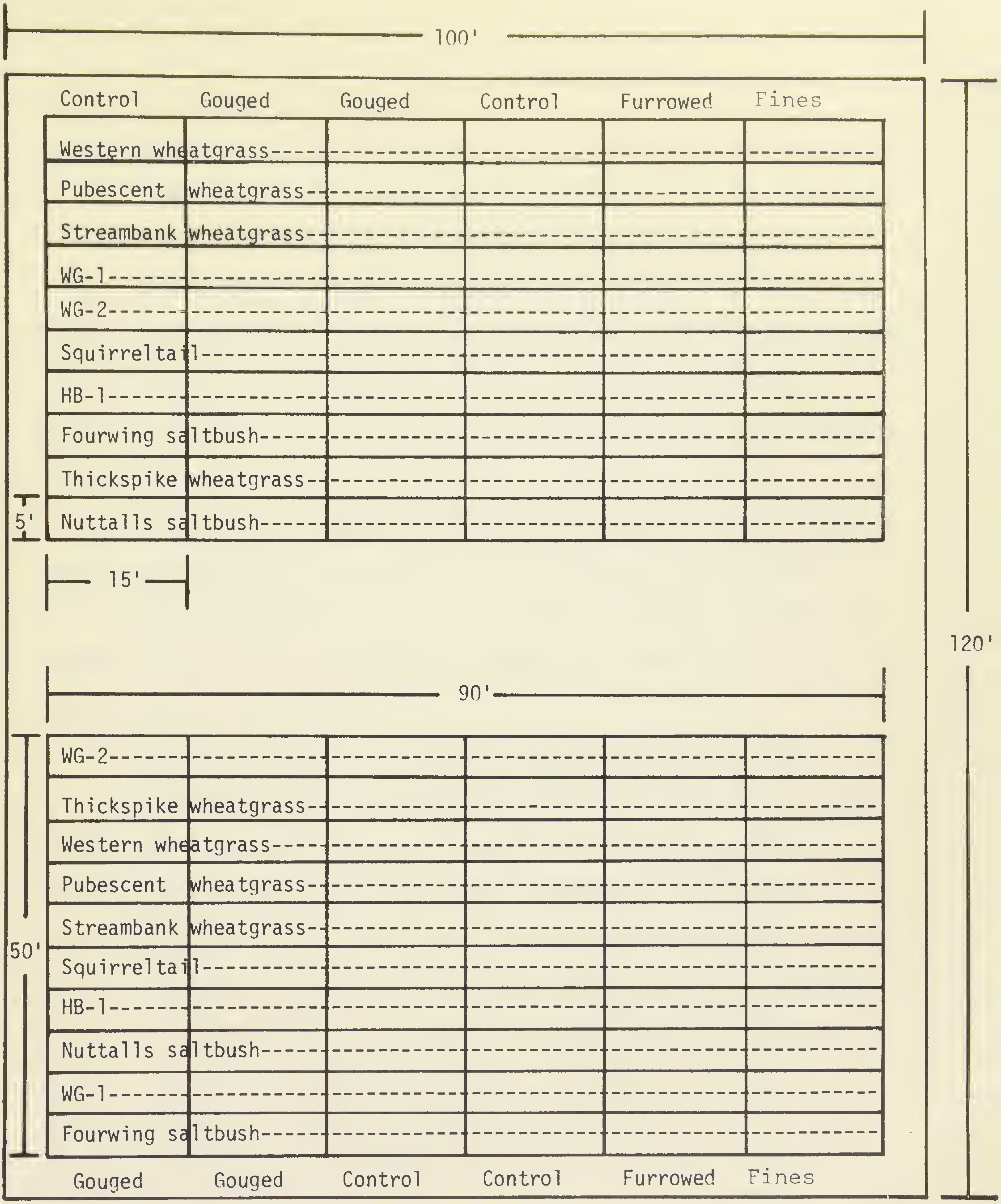


Figure 7. Addition of limestone fines to the Warren Plot.

SOILS

Soil samples were taken first from various bentonite mining areas and then from the experimental plots. Each sample was analyzed for the following soil parameters:

1. pH



Scale 1" = 15'

FIGURE 6. WARREN TEST PLOT DESIGN.

2. Phosphorus
3. Potassium
4. Electrical Conductivity
5. Calcium
6. Magnesium
7. Sodium
8. Texture

All analyses were done at the Montana State University (MSU) soils laboratory.

The soils on the experimental plots were sampled on a grid to measure the soil variability. Initially nine samples were taken; however, since the variability was low, the number of samples was reduced.

Soil samples were taken at various depths on unmined areas. Premining samples were taken from the surface (0 to 6 inches), the subsurface (6 to 18 inches), and the overburden layers (over 18 inches, taken from the highwall of a pit). On regraded areas samples were taken only from the topsoil and the overburden.

During the growing season, soil-moisture measurements from the surface and the subsurface were made. Percent moisture was measured by taking a soil sample, weighing it, oven drying, and then reweighing it. Moisture was expressed as a percentage by subtracting the oven-dried weight from the wet weight, and by dividing the difference by the oven-dried weight. Originally, samples were taken and shipped to MSU for weighing and drying. This proved unsatisfactory because it required returning to the lab soon after the sample was taken. A new method was then devised: the samples were weighed in the field, transported in a twirl-loc bag, dried in a kitchen oven, and reweighed. This method proved satisfactory.

EXPERIMENTAL VARIABLES

The effects on revegetation of the following three variables were tested on all plots:

1) surface treatments

2) seeding rate

3) adaptability of individual species

Originally, the effects of spring and fall seedings were to be measured on all plots, but inclement weather did not allow fall seeding at Warren, Greybull, Upton, and Vananda. An additional plot was constructed at Colony to test the effects of fertilization.

Cost and practicality were also considered. Thus, although other techniques were available to mitigate adverse conditions, such as soils ammendments, mulching, and irrigation, these techniques were not utilized.

Surface Treatments

All plots, prior to being administered surface treatments, were rototilled to a depth of 4 inches using a 12-horsepower John Deere garden tractor, the result of which was a loose, manageable seed bed (Figure 8).

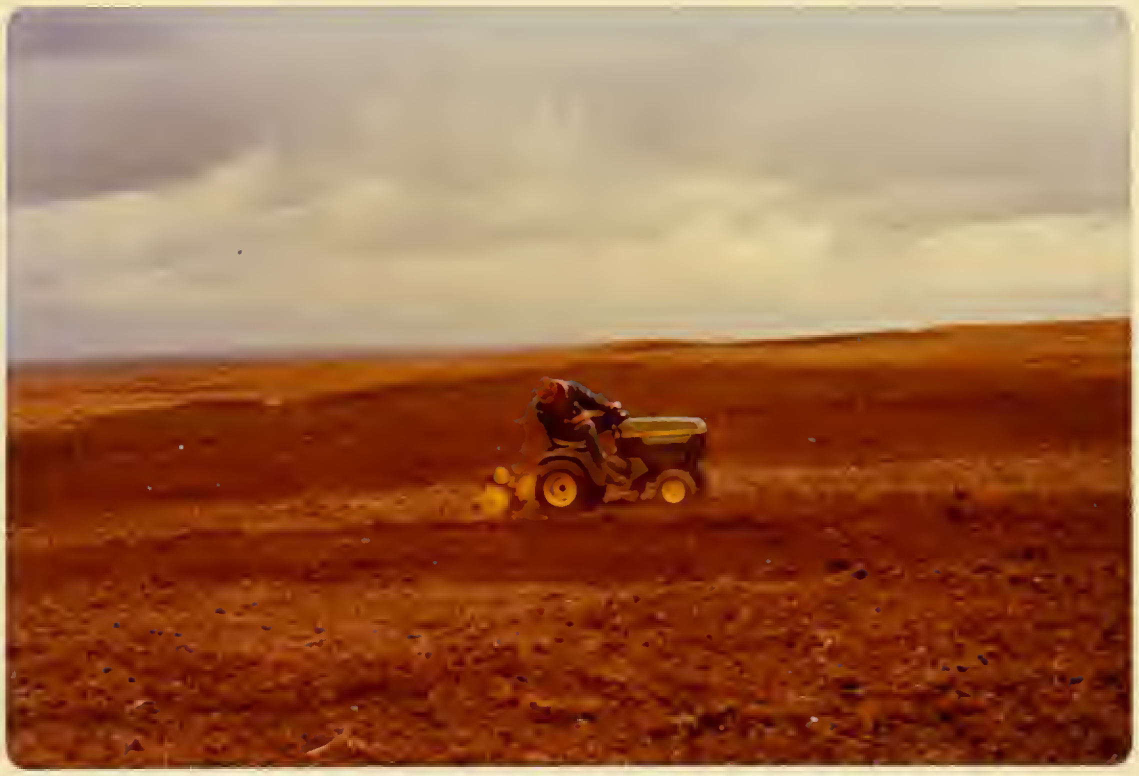


Figure 8. Seed bed preparation by rototilling.

Surface treatments were administered in an attempt to increase the soil moisture available to the plants. It was hoped that these treatments would overcome the problem of low infiltration rates by preventing run-off; this allowed a longer infiltration period. Two kinds of surface treatment were used: deep furrowing and gouging. In addition, control areas were established for the purpose of comparison.

Four subplots in each plot were deep furrowed, and four were gouged, with four being used as controls. The remaining four were deep furrowed but seeded with mixtures at varying rates.

Deep Furrowing. The deep-furrowing surface treatment similated the use of a deep-furrow drill. The furrows were cut with a device consisting of five-10 inch plow sweeps (duck-feet type plow shoes) welded on a steel frame perpendicular to the ground surface. This device was pulled with the garden tractor, or when necessary, manually (Figure 9). The furrows were cut on 12-inch centers; an opening was made at the base of the furrow, the seed dropped in, and the opening closed. An attempt was made throughout to minimize disturbance to the furrow.

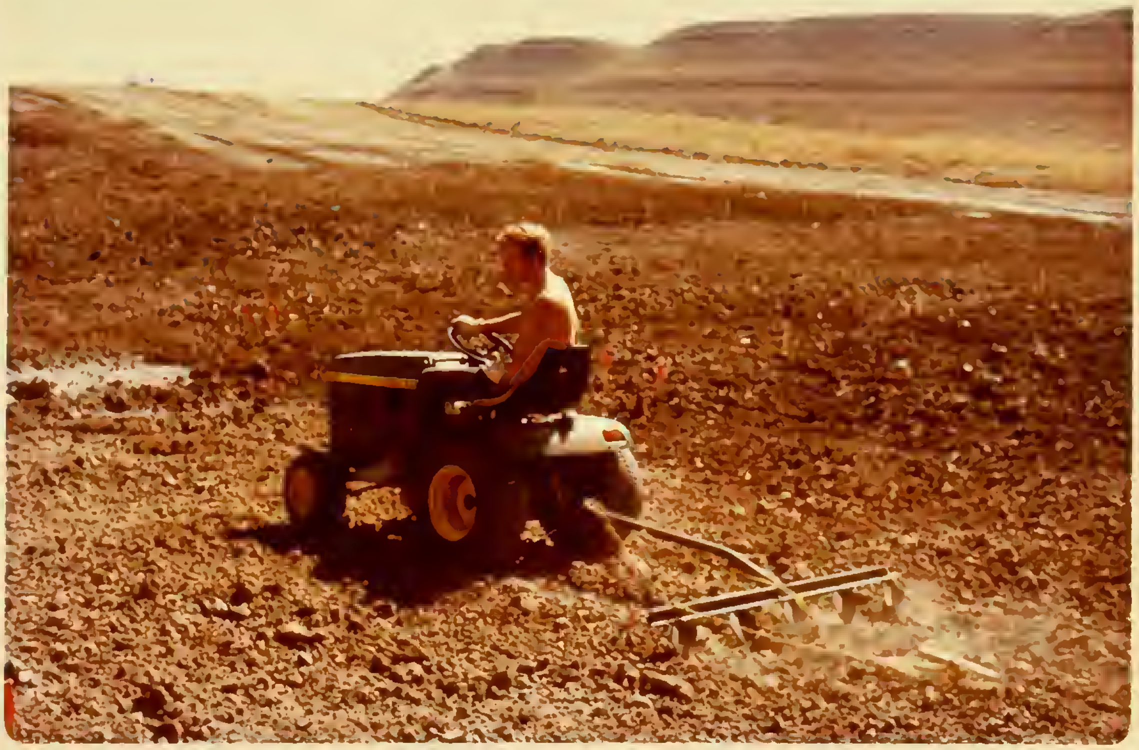


Figure 9. Deep furrowing surface treatment.

Gouging. The gouging surface treatment involved one of two methods: where possible a mechanical gouger was used; otherwise gouges were dug by hand.[1] The mechanical gouger consisted of a 10-inch steel plow disc welded to a steel frame perpendicular to the line of travel (Figure 10).[2] The apparatus was then attached to a 12-horsepower John Deere garden tractor. Gouged areas were broadcast seeded at twice the drill rate, and the seed then compressed into the ground.

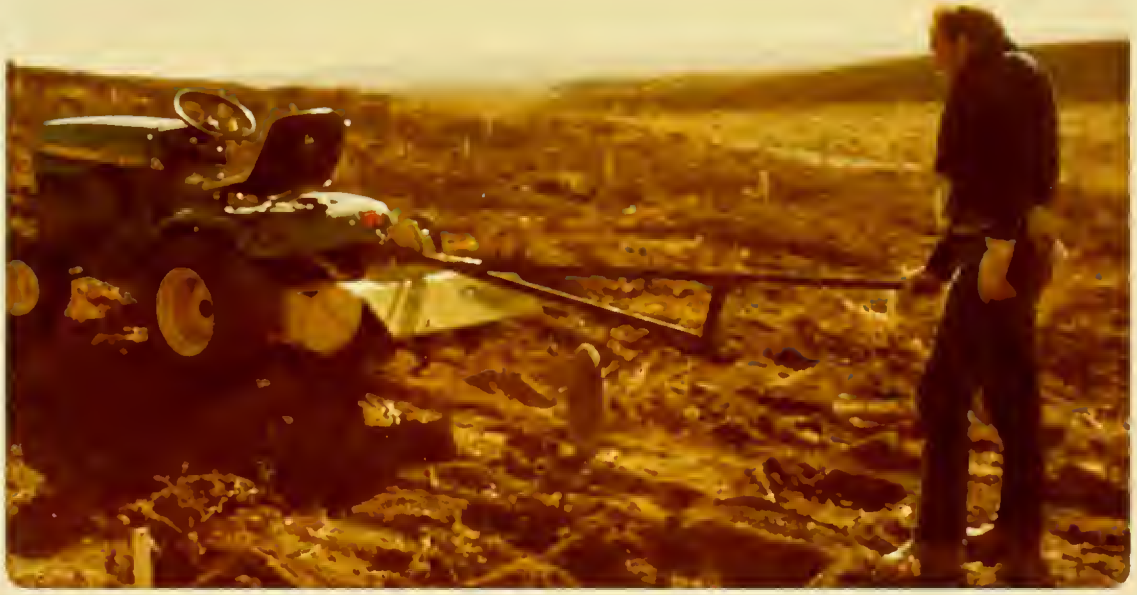


Figure 10. Gouging surface treatment.

Control areas were seeded using the furrowing device to open a furrow approximately 1-inch deep, placing the seed in by hand, and then closing the furrows, leaving a flat surface (Figure 11).

---

[1] This technique was described in a study by Sindelar et al., 1973.

[2] Essentially this was a smaller version of that employed by Sindelar.

Figure 11. Seeding the plots.

Seeding Rates

Microplots in the gouged, furrowed, and control subplots were each randomly assigned a plant species; while microplots in the furrowed mixture subplots were assigned a mixture and a seeding rate. Control, gouged, and deep-furrowed microplots were planted with 7 pounds of seed per acre for grasses and one seed per square foot for shrubs (both figures are in pure live seed). The seeding rate in these plots was kept low so that the effects of surface treatment and the ability of a species to survive were measured, without the added variable of plant competition.

For purposes of evaluating this competition, several mixtures of seed were planted. These mixtures consisted of varying combinations of grass and forb species that mining companies were already using on their reclamation sites. The effect of the seeding rate was tested by planting these mixtures on a deep-furrowed surface at the following rates: the recommended rate; one-half the recommended rate; three-quarters; one and

one-half; and twice the recommended rate. The areas seeded with these mixtures were termed furrowed-mixture areas.

Adaptability of Individual Species

The species were selected for drought and salinity tolerance. Species vary slightly from area to area as a result of varying annual precipitation rates and moisture requirements of the plants. Tables 1 through 4 present the species seeded on each plot.

Fertilization

At Colony, Wyoming, the effect of fertilization was measured at an additional plot, which was constructed adjacent to the initial plot. All 16 of the subplots were deep furrowed and seeded with individual species. At the beginning of the first growing season, 16-20-0 fertilizer[1] was applied at rates of 0, 100, and 150 pounds of available nitrogen per acre.

Seasons of Seeding

Microplots in some of the plots were assigned to each of spring and fall seedings for the purpose of evaluating the importance of season of seeding. The following plots were seeded in both spring and fall:

Alzada - Oct. 29, 1975 and March 23, 1976

Colony - Oct. 30, 1975 and March 27, 1976

Glasgow - October 22, 1975 and April 7, 1976

The following plots were seeded only in spring or fall:

Greybull - April 4, 1976

Upton - May 13, 1976

Vananda - March 29, 1976

Warren - October 30, 1976

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[1] This nomenclature means 16 percent nitrogen, 20 percent phosphorus, 0 percent potassium.

Table 1. Species and mixtures seeded at Alzada, Montana - Colony and Upton, Wyoming

Common Name	Scientific Name	Abbreviation
Yellow sweet clover	*Melilotus officinalis*	Meof
White prairie clover	*Petalostemon candidum*	Peca
Crested wheatgrass (Nordan)	*Agropyron desertorum*	Agde
Crested wheatgrass (Fairway)	*Agropyron cristatam*	Agcr
Western wheatgrass	*Agropyron smithii*	Agsm
Pubescent wheatgrass	*Agropyron trichophorum*	Agtri
Streambank wheatgrass	*Agropyron riparium*	Agri
Siberian wheatgrass	*Agropryon sibiriam*	Agsi
Thickspike wheatgrass	*Agropyron dasystochium*	Agda
Basin wildrye	*Elymus cinereus*	Elci
Buffalo grass	*Buchloe dactyloides*	Buda
Indian ricegrass	*Oryzopsis hymenoides*	Orhy
Big sage	*Artemesia tridentata*	Artr
Fourwing saltbush	*Atriplex canescens*	Atca
Nuttalls saltbush	*Atriplex nuttallii*	Atnu
Greasewood	*Sarcoleatus vermicutatus*	Save
Rubber rabbitbrush	*Chrysothamnus nauseosus*	Chna
Canadian wildrye	*Elymus canadensis*	Elca
Bottlebrush squirreltail*	*Sitanion hystrix*	Sihy
Shadscale saltbush*	*Atriplex confertifolia*	Atco

* seeded at Upton, Wyoming only

Mixtures

ACU-1 -	Western wheatgrass	6 lb./acre
	Green needlegrass	4 lb./acre
	Yellow sweet clover	2 lb./acre
		12 lb./acre
ACU-2 -	Thickspike wheatgrass	3 lb./acre
	Western wheatgrass	6 lb./acre
	Green needlegrass	4 lb./acre
	Yellow sweet clover	2 lb./acre
		15 lb./acre
RP-1 -	Western wheatgrass	6.0 lb./acre
	Pubescent wheatgrass	4.5 lb./acre
	Green needlegrass	4 lb./acre
	Yellow sweet clover	.5 lb./acre
		15.0 lb./acre

Table 2. Species and mixtures seeded at Glasgow and Vananda, Montana

Common Name	Scientific Name	Abbreviation
Yellow sweet clover	*Melilotus officinalis*	Meof
White prairie clover	*Petalostemon candidum*	Peca
Crested wheatgrass (Nordan)	*Agropyron desertorum*	Agde
Crested wheatgrass (Fairway)	*Agropyron cristatam*	Ager
Western wheatgrass	*Agropyron smithii*	Agsm
Pubescent wheatgrass	*Agropyron trichophorum*	Agtr
Streambank wheatgrass	*Agropyron riparium*	Agri
Siberian wheatgrass	*Agropyron sibiriam*	Agsi
Thickspike wheatgrass	*Agropyron dasystachium*	Agdn
Basin wildrye	*Elymus cinereus*	Elci
Buffalo grass	*Buchloe dactyloides*	Buda
Indian ricegrass	*Oryzopsis hymenoides*	Orhy
Big sage	*Artemisia tridentata*	Artr
Rubber rabbitbrush	*Chrysothamnus nauseosus*	Chna

Mixtures

GV-1 -	Western wheatgrass	8 lb./acre
	Green needlegrass	3 lb./acre
	Thickspike wheatgrass	5 lb./acre
	Yellow sweet clover	2 lb./acre
		17 lb./acre

RP-1 -	Western wheatgrass	6 lb./acre
	Pubescent wheatgrass	4.5 lb./acre
	Green needlegrass	4 lb./acre
	Yellow sweet clover	.5 lb./acre
		15.0 lb./acre

Table 3. Species and mixtures seeded at Greybull, Wyoming

Common Name	Scientific Name	Abbreviation
Crested wheatgrass (Nordan)	Agropyron desertorum	Agde
Crested wheatgrass (Fairway)	Agropyron cristatam	Agcr
Western wheatgrass	Agropyron smithii	Agsm
Pubescent wheatgrass	Agropyron trichophorum	Agtri
Streambank wheatgrass	Agropyron riparium	Agri
Thickspike wheatgrass	Agropyron dasystachium	Agda
Siberian wheatgrass	Agropyron sibiriam	Agsi
Basin wildrye	Elymus cinereus	Elci
Indian ricegrass	Oryzopsis hymenoides	Orhy
Bottlebrush squirreltail	Sitanion hystrix	Sihy
Big sage	Artemesia tridentata	Artr
Fourwing saltbush	Atriplex canescens	Atca
Nuttalls saltbush	Atriplex nuttallii	Atnu
Shadscale saltbush	Atriplex confertifolia	Atco
Greasewood	Sarcobatus vermiculatus	Save
Rubber rabbitbrush	Chrysothamnus nauseosus	Chna
Winterfat	Ceratoides lanata	Cela
Shadscale saltbush (Native)	Atriplex confertifolia	Atco
Alkali sacaton	Sporobolus airoides	Spai
Bottlebrush squirreltail(Native)	Sitanion hystrix	Sihy

Mixtures

WG-1 -	Western wheatgrass	4 lb./acre
	Crested wheatgrass	4 lb./acre
	Indian ricegrass	3 lb./acre
		11 lb./acre

WG-2 -	Western wheatgrass	3 lb./acre
	Thickspike wheatgrass	3 lb./acre
	Nuttalls saltbush	1 lb./acre
		7 lb./acre

RP-1 -	Western wheatgrass	6 lb./acre
	Pubescent wheatgrass	4.5 lb./acre
	Green needlegrass	4 lb./acre
	Yellow sweet clover	.5 lb./acre
		15.0 lb./acre

Table 4. Species and mixtures seeded at Warren, Montana

Common Name	Scientific Name	Abbreviation
Western wheatgrass	*Agropyron smithii*	Agsm
Pubescent wheatgrass	*Agropyron trichophorum*	Agtri
Streambank wheatgrass	*Agropyron riparium*	Agri
Thickspike wheatgrass	*Agropyron dasystachium*	Agda
Bottlebrush squirreltail	*Sitanion hystrix*	Sihy
Fourwing saltbush	*Atriplex canescens*	Atca
Nuttalls saltbush	*Atriplex nuttallii*	Atnu

Mixtures

Mixture	Species	Rate
WG-1 -	Western wheatgrass	4 lb./acre
	Crested wheatgrass	4 lb./acre
	Indian ricegrass	3 lb./acre
		11 lb./acre

Mixture	Species	Rate
WG-1 -	Western wheatgrass	3 lb./acre
	Thickspike wheatgrass	3 lb./acre
	Nuttalls saltbush	1 lb./acre
		7 lb./acre

MEASUREMENT OF RESULTS

Three parameters were used to measure plant growth results:

1. Productivity - measured by clipping and weighing all planted species growing in the top left-hand quarter of the microplot (Figure 12).

2. Canopy Cover - measured by estimating the percentage of ground cover by plants for the entire microplot (Figure 13).

3. Stems per unit area - measured by counting the stems as they were clipped.

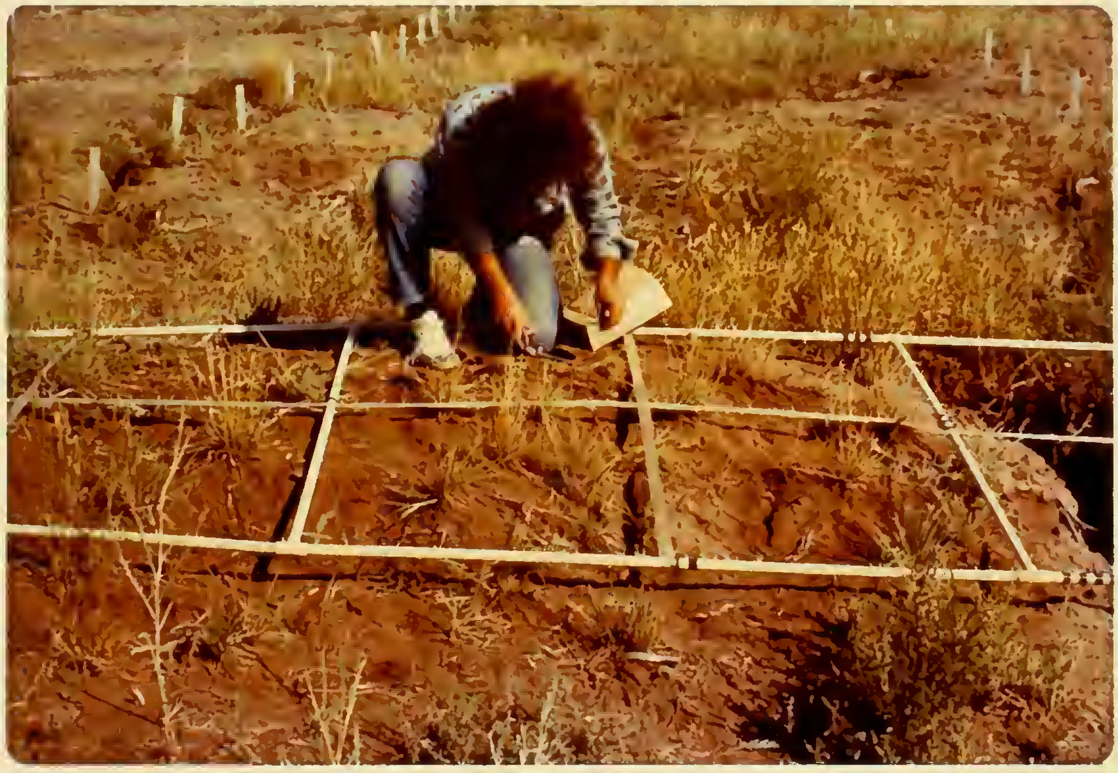

Figure 12. Clipping and counting stems on the plots.

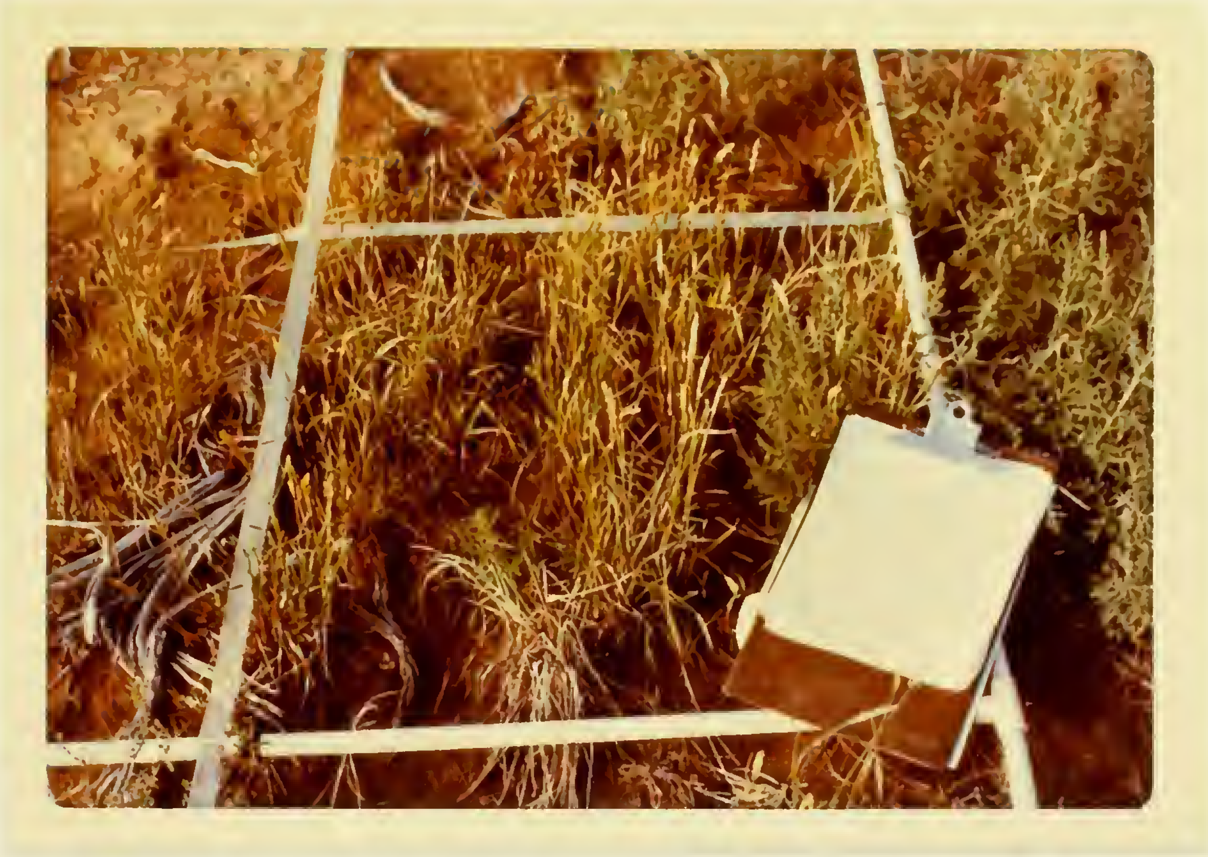

Figure 13. Estimating canopy cover.

RESULTS AND DISCUSSION

The quantitative data in this section have been kept to a minimum in order to present the results in as clear and concise a format as possible. (Complete quantitative data are presented in the appendices and marked for easy reference to the following discussion.) The amount of raw data has likewise been kept to a minimum.[1/]

SURFACE TREATMENTS

Furrowed and gouged subplots were compared to the control subplots for all plots with measurable vegetation. Only those species which produced consistent stands of vegetation were utilized in the analysis. The differences were measured for their significance using the Student's t test at the 95 percent probability level.

[1/] Copies of the raw data may be obtained by writing to the Montana Department of State Lands, Capitol Station, Helena, MT 59601.

There was little overall difference between subplots assigned surface treatments and those which served for a control. Two species showed a significant increase in production on the forrowed subplots, while one showed a significant decrease. On these subplots no difference in canopy cover was measured. On gouged subplots one species increased production while one decreased it, and two had significantly greater canopy cover while one had less. These results are summarized below.

Table 5. Significant effects of surface treatments.

Surface Treatments / Species	Production		Canopy Cover	
	Furrowed	Gouged	Furrowed	Gouged
Fairway Crested Wheatgrass		increase		increase
Indian ricegrass		decrease		decrease
Nordan Crested Wheatgrass				increase
Pubescent Wheatgrass	increase			
Streambank Wheatgrass	increase			
Western Wheatgrass	decrease			

(Blank spaces indicate insignificant differences.)

Evidently, the surface treatments of deep furrowing and gouging fail to increase plant vigor because both treatments involve disturbing topsoil to a depth which may bring seed and/or roots in contact with undesirable materials (such as overburden or cleanings). It is possible that by bringing undesirable or toxic materials to the surface reclamation would be less successful. This contact with undesirable materials was exhibited at the Warren site where bentonitic material could be seen swelling at the bottom of the gouges. Gouging and furrowing did increase

the moisture available to plants, made evident on many plots by the thick growth of weeds in both the furrows and the gouges (Figure 14); and by the water trapped in the gouges (Figure 15).

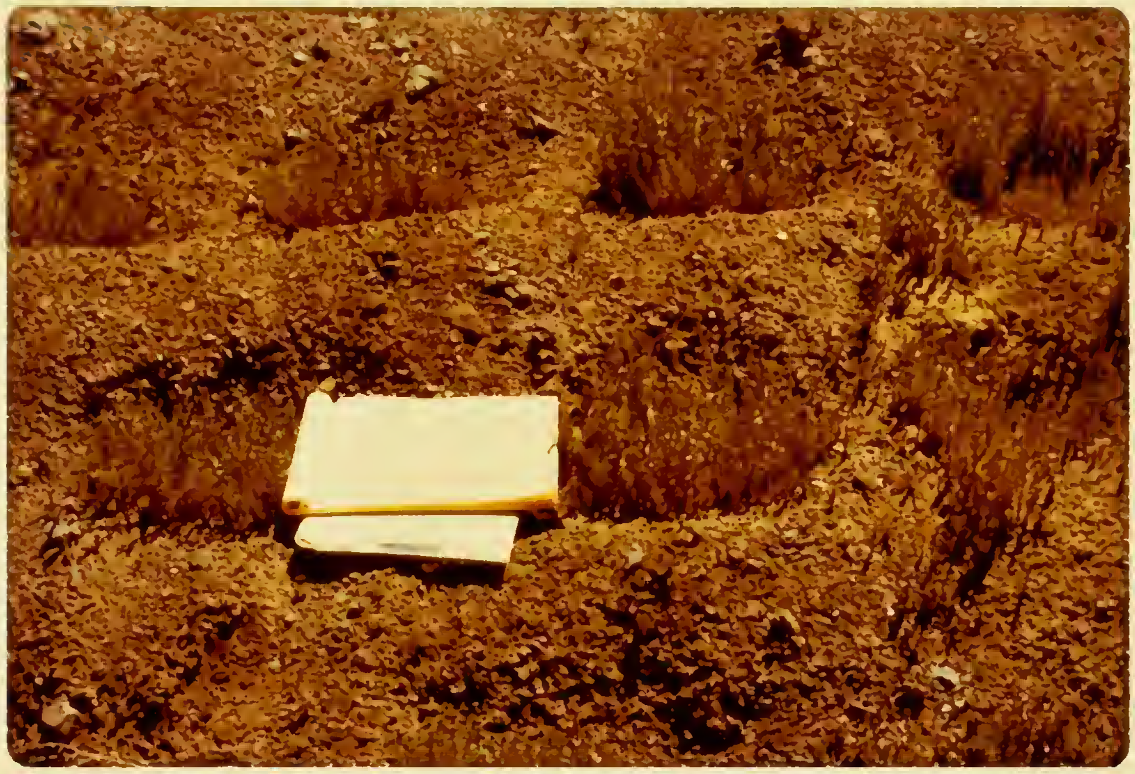

Figure 14. Vigorous weed growth in gouges.

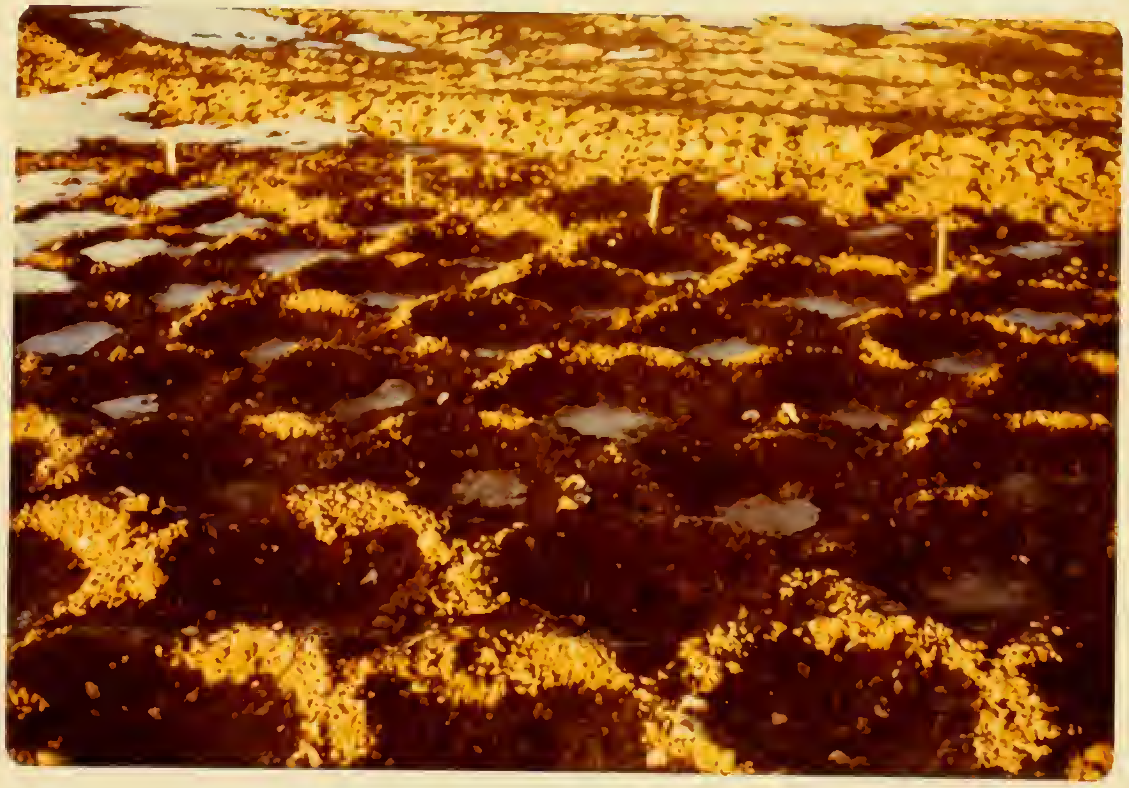

Figure 15. Water retention in gouges.

SEEDING RATE

Seeding rates greater than those recommended did not have a significant effect on production or canopy cover, while seeding rates below those recommended produced consistantly poorer stands. This study found that a rate of 12 to 15 pounds per acre is optimal.

ADAPTABILITY OF INDIVIDUAL SPECIES

Of the wheatgrasses, Nordan and Fairway crested, Thickspike, Streambank, and Western grew most consistently. The wildryes, Basin and Canadian, grew less consistently. Site-to-site variability is so great that species should not be compared to one another for all sites simultaneously.

Plot Analysis

An analysis of species at individual plots follows.

Vananda. Little or no seeded vegetation was growing on the Vananda Plot at the end of the 1976 growing season (Figure 16). Soil electrical conductivity (E.C.) ranged from 7.2 to 19 millimhos and the S.A.R. ranged from 22.27 to 49.47. When the plot was initially established, the site contained annual forbs and a few perennial grasses, and the topsoil appeared in good condition. Today, after two years, most of the plot is covered with salts and bentonite-contaminated material (Figure 17). Evidently the cleanings were placed on top of the spoils and below the topsoil; during rototilling of the site, the cleanings were inadvertantly mixed with the topsoil, thus creating soils of poorer quality.

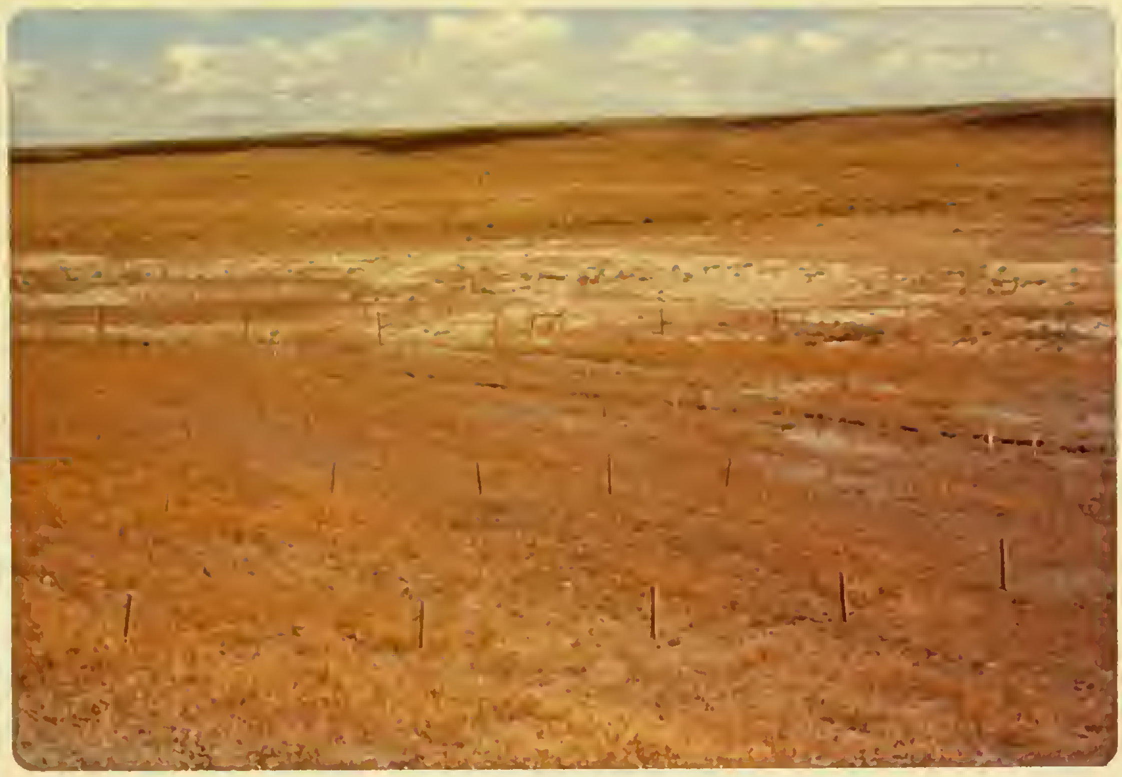

Figure 16. Vananda Plot at the end of the 1976 growing season.

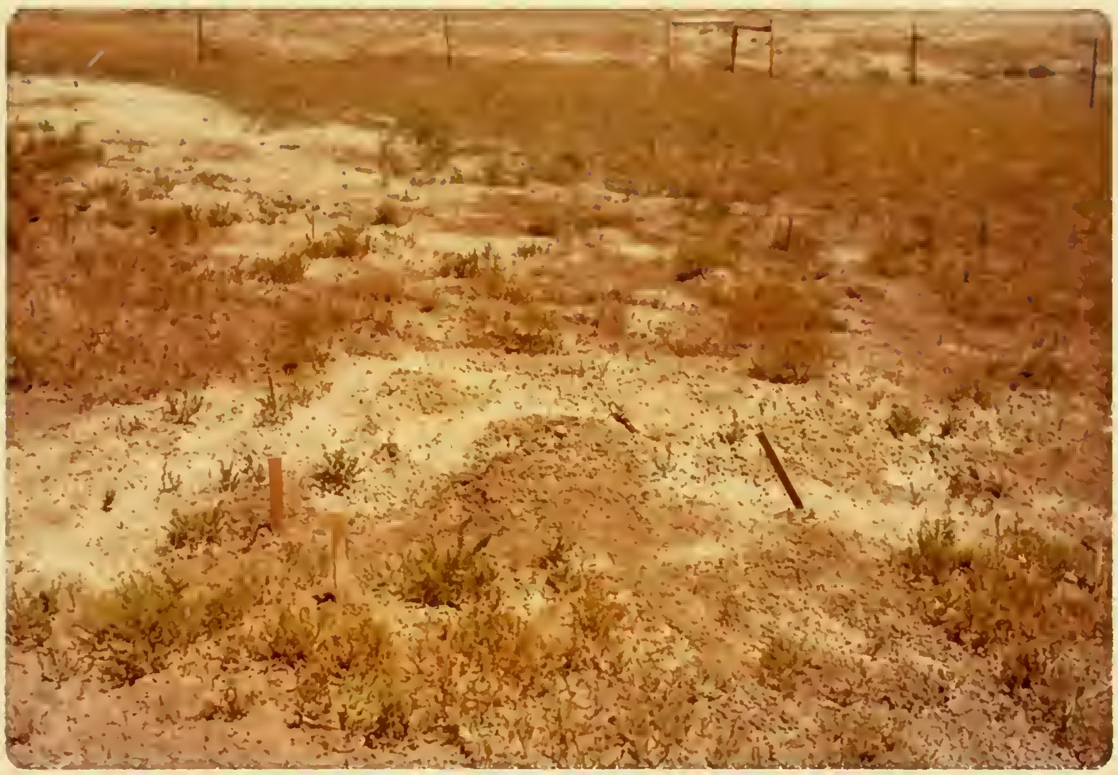

Figure 17. Salts and bentonitic material on the surface of the Vananda Plot.

Greybull. At the end of the 1977 growing season, there were few or no seeded species on the Greybull Plot (Figure 18). During June of 1976 a number of species had begun to grow, but by the end of July none of the seeded species could be found. Two factors have contributed to this failure: poor soils and low precipitation. The soils here are sodic and very saline (the electrical conductivity ranged from 14.8 millimhos to 39.7 millimhos). The total precipitation for 1976 was 9.34 inches (with over three inches falling in one storm). The effects of the low precipitation were intensified by spring seeding.

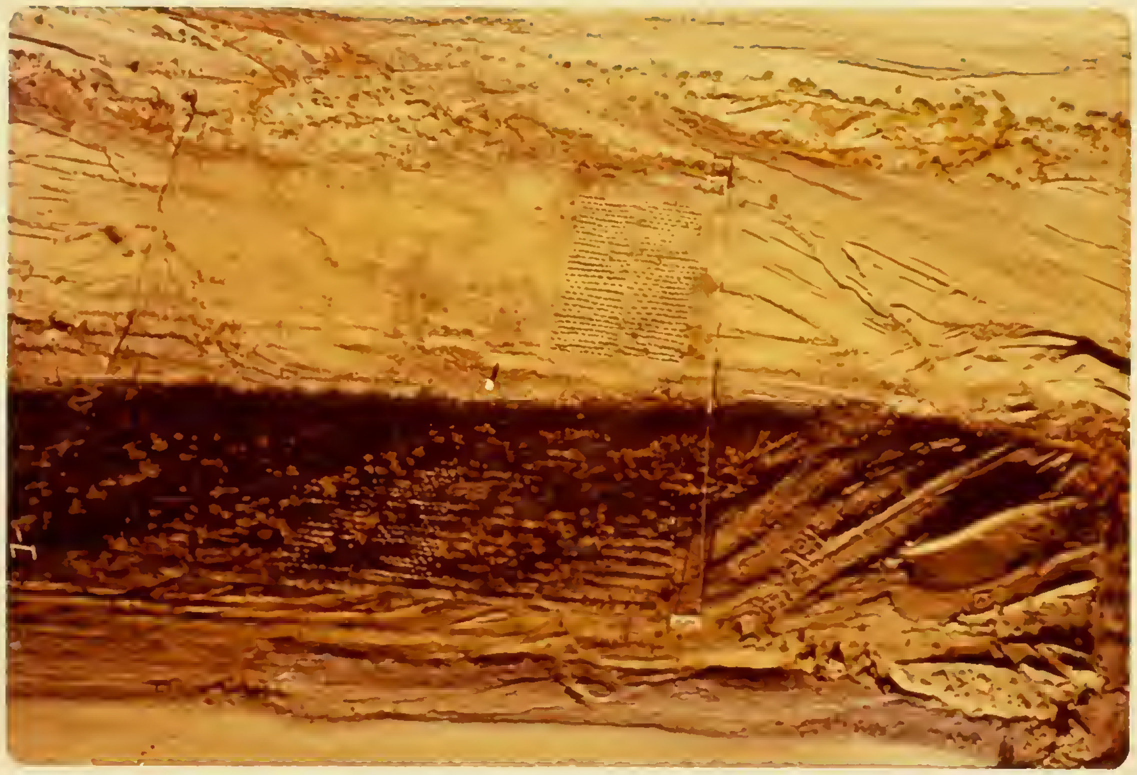

Figure 18. Aerial view of the Greybull Plot.

At the conclusion of the study, a significant number of Nuttall (Gardner) saltbush plants had reinvaded the site naturally.

Warren. At the end of the 1977 growing season, there was no vegetation on the Warren Plot (Figure 19). Highly sodic and saline soils, coupled with low precipitation (approximately 6 inches), makes this an extremely

difficult site to revegetate (Figure 20). Electrical conductivities ranged from 11.2 to 18.4 millimhos. Sodium Adsorption Ratios ranged from 55.34 to infinity.

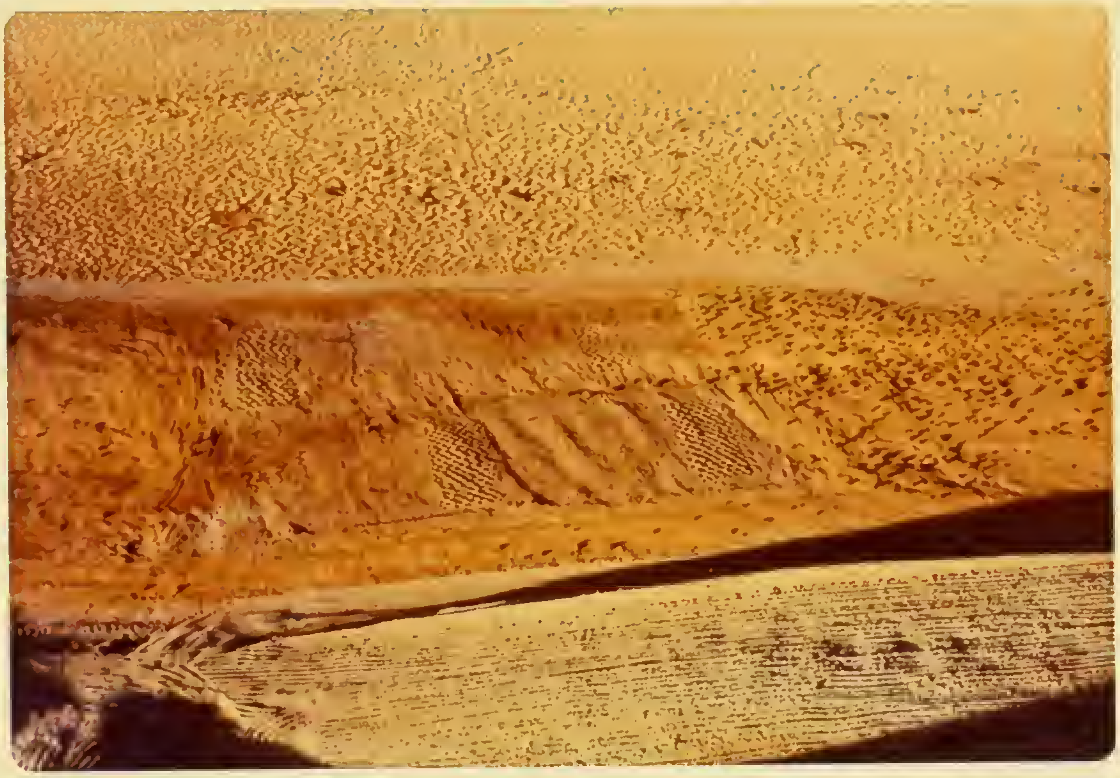

Figure 19. Aerial view of the Warren Plot.

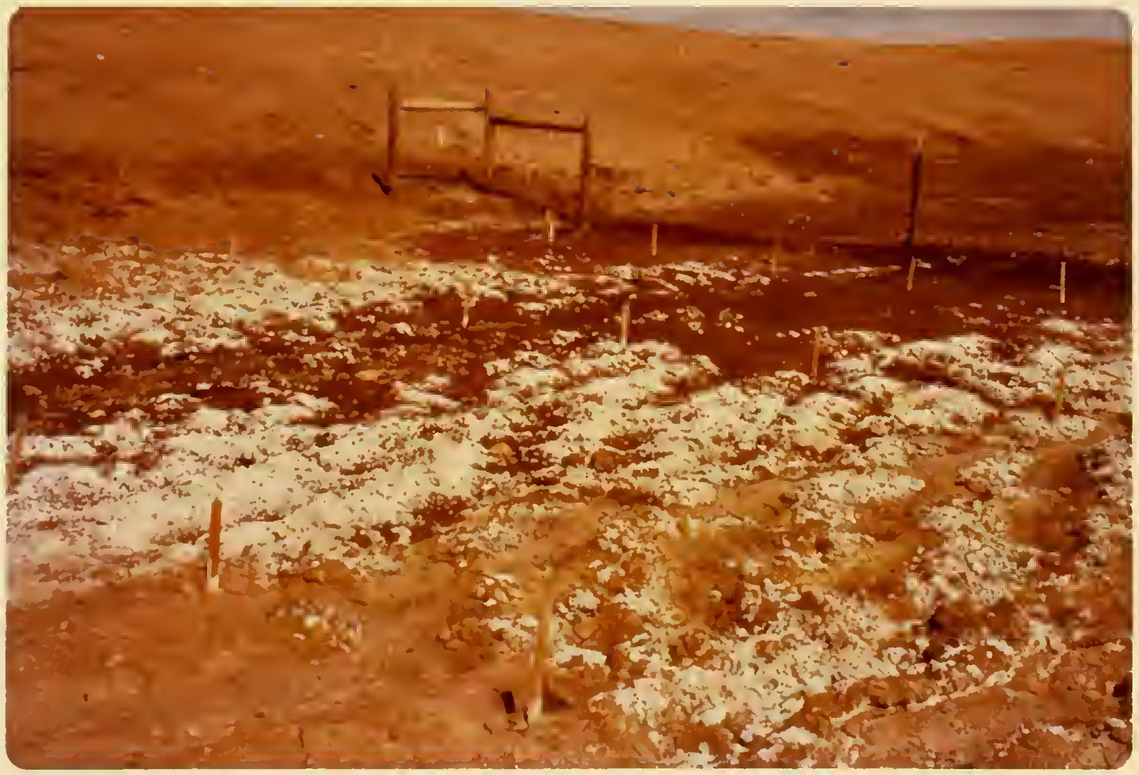

Figure 20. Salts on the surface of the Warren Plot.

Alzada. Three seeding mixtures and 17 individual species were planted in the Alzada microplots. The most productive individual species and, in general, the ones providing the greatest amount of canopy cover were the wheatgrasses, particularly Nordan and Fairway crested, and Western. Thickspike wheatgrass, although not as productive as Western, provided more cover. The following grasses, although even less productive, did grow at all of the test plots: Indian ricegrass, Basin wildrye, Canadian wildrye, Siberian wheatgrass, Pubescent wheatgrass, and Streambank wheatgrass. In spite of poorer production these species should not be eliminated for consideration on reclamation sites: they do grow and provide some of the diversity that one hopes reclamation will achieve. (See Figure 21 for a picture of the Alzada plot.)

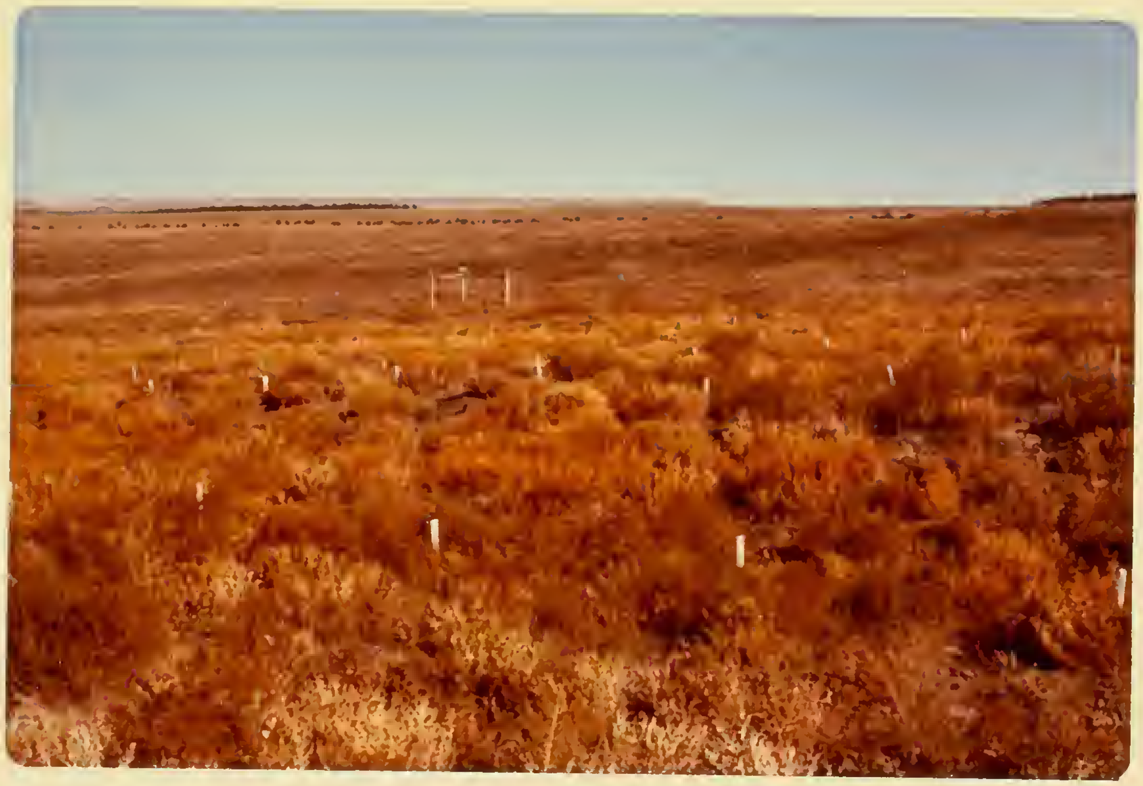

Figure 21. Alzada Plot at the end of the 1976 growing season.

Of the shrubs seeded at the Alzada plot, only Greasewood was successfully established (Figure 22), and of the forbs, only Yellow sweet

clover. As a result of grasshopper damage, Yellow sweet clover production and canopy cover were reduced, and consequently measurements were underestimated.

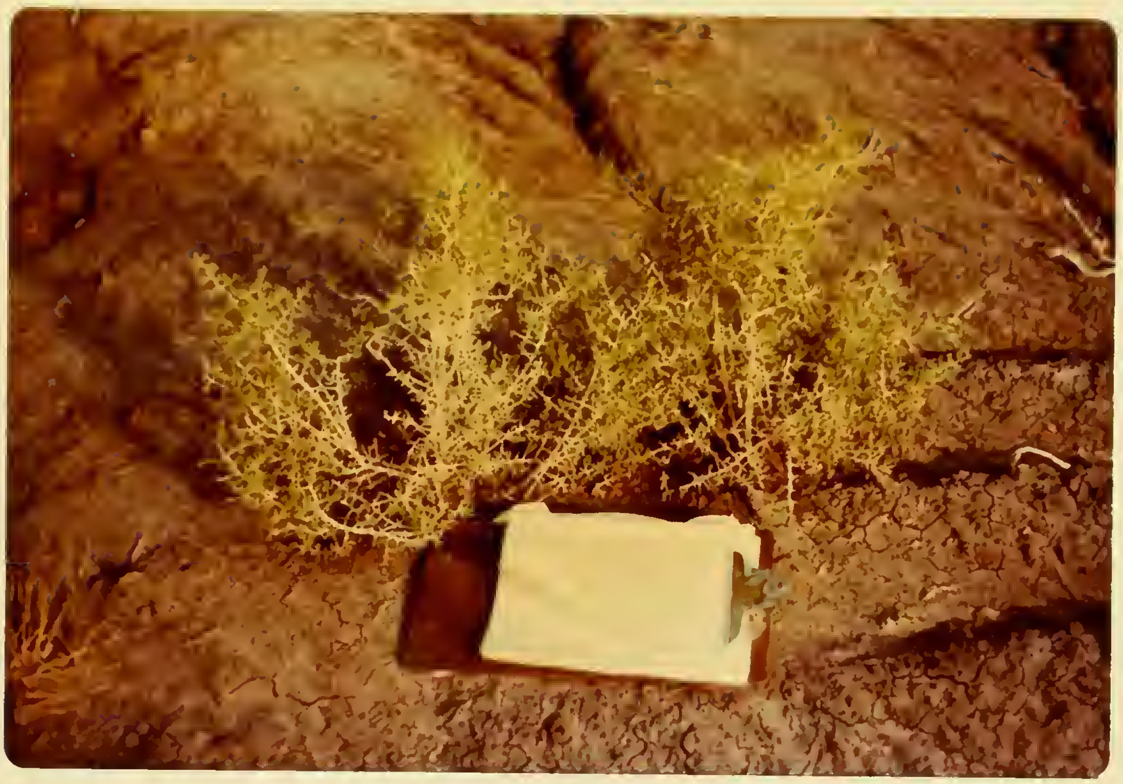

Figure 22. Greasewood growing at the Alzada Plot.

The following species failed to become established at all: Nuttall's saltbush, Big sage, Rubber rabbitbrush, Fourwing saltbush and White prairie clover.

Colony. The Colony site was seeded with the same mixtures and individual species as those used at Alzada. Nordan and Fairway crested were here the most successful species, followed closely by Thickspike wheatgrass. Intermediately successful were the remaining wheatgrasses: Pubescent, Western, Streambank, and Siberian. Least successful, again, were the wildryes and Indian ricegrass. Greasewood was the only shrub to survive. The following species were unsuccessful altogether: the saltbushes, Rubber rabbitbrush, Big sage, Buffalo grass, and White prairie clover. The production and canopy cover for all species were greater here at Colony than at Alzada as a result of the better quality soils.

Upton. The Upton Plot was seeded with the same mixtures and species used at the Alzada and Colony plots, with the addition of Shadscale, Winterfat, and Squirreltail. Due to the soil condition and the climate, however, the overall results at Upton are quite different (Figure 23).

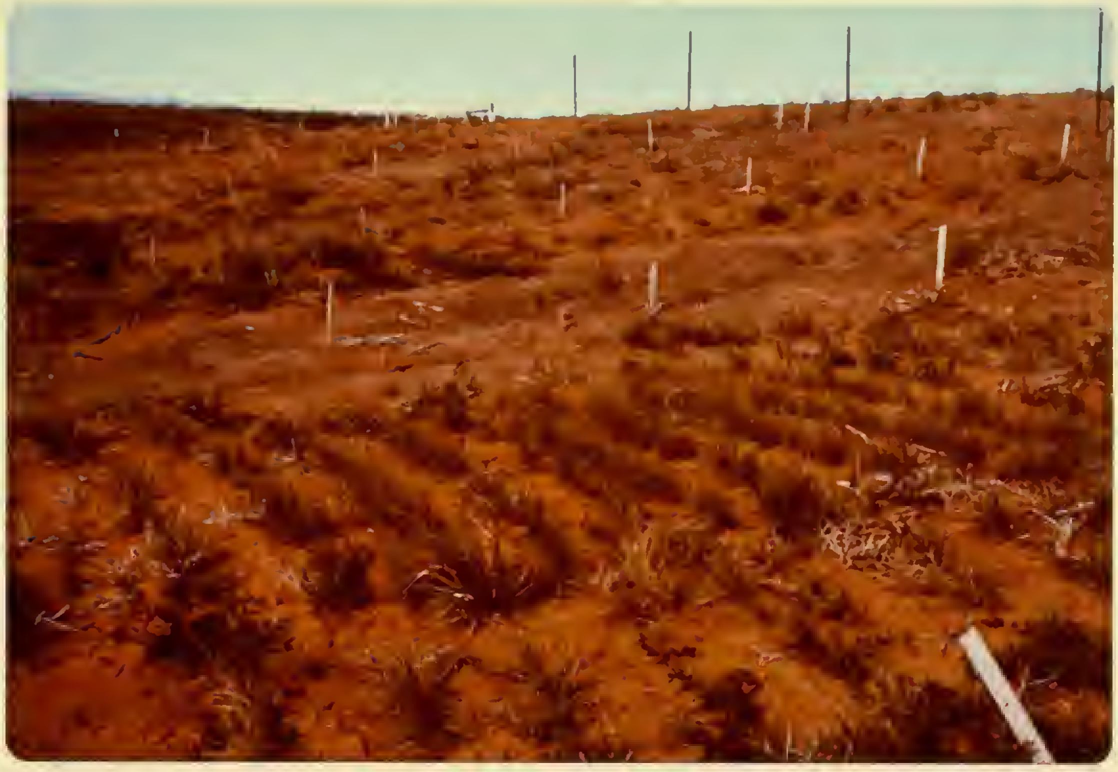

Figure 23. Ground view of the Upton Plot.

The most productive species was Nordan crested wheatgrass, followed by Thickspike, Fairway crested, Pubescent, Streambank, and Western. The next most productive were Siberian, Canadian wildrye, and Squirreltail, while the least productive were Basin wildrye and Indian ricegrass. No production of Buffalo grass was measured because it was thought sampling would be too destructive; present visual estimations nonetheless indicate production is low. Although Squirreltail was not the most productive species, it did have the second highest canopy cover.

Greasewood, again, was the most successful shrub. Also growing here were, in order of decreasing abundance, Fourwing and Nuttall's saltbush, and Big sage. Yellow sweet clover was more successful at the Upton Plot than at any of the others, while Buffalo grass, the saltbushes,

Big sage, and White prairie clover survived here and nowhere else. The success of so many species at Upton is due, in large measure, to the better soil conditions. In fact the only species to not grow were Shadscale saltbush and Winterfat.

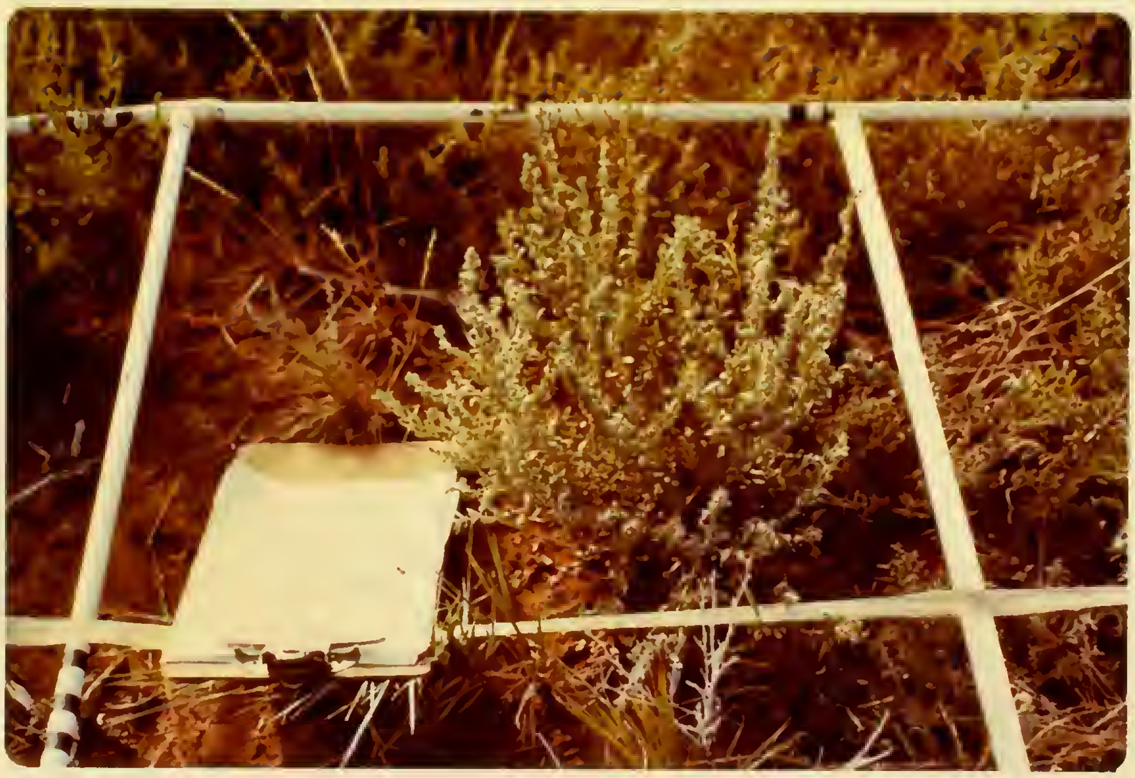

Figure 24. Fourwing saltbush growing at the Upton Plot.

Glasgow. At the Glasgow Plot, two seeding mixtures and 14 individual species were used. The most successful species under Glasgow's site conditions were, in decreasing order, Thickspike, Fairway crested, and Streambank wheatgrasses. Almost as successful were Western and Pubescent, followed by Nordan crested and Basin wildrye, while Indian ricegrass grew insignificantly. Yellow sweet clover was successful, but again evaluation was hindered by heavy grasshopper infestation and by rabbit browsing. Big sage, Rubber rabbitbrush, Buffalo grass, and White prairie clover did not grow here, while the saltbushes, Canadian wildrye, and Greasewood were not planted in the first place.

Figure 25. Ground view of the Glasgow Plot.

FERTILIZATION

No significant differences were measured on seeded species between the fertilized and unfertilized plots. Summer cypress (Kochia scoparia) was the only plant which responded positively to fertilization (Figure 26). While Summer cypress infested the entire Colony area, infra-red aerial photographs indicated more vigorous Summer cypress growth on fertilized subplots (Figure 27).

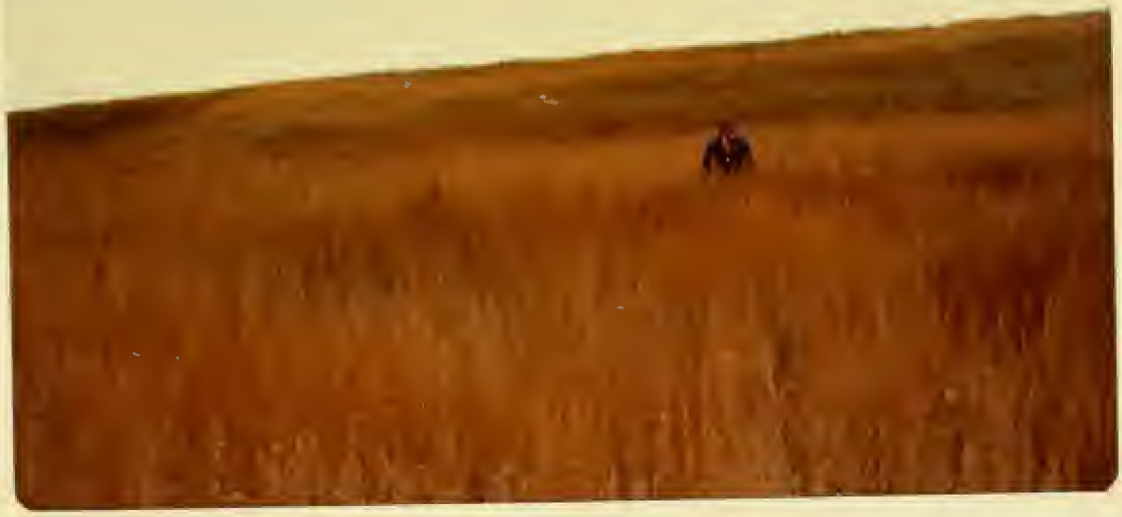

Figure 26. Summer cypress infestation of the Colony Plot.

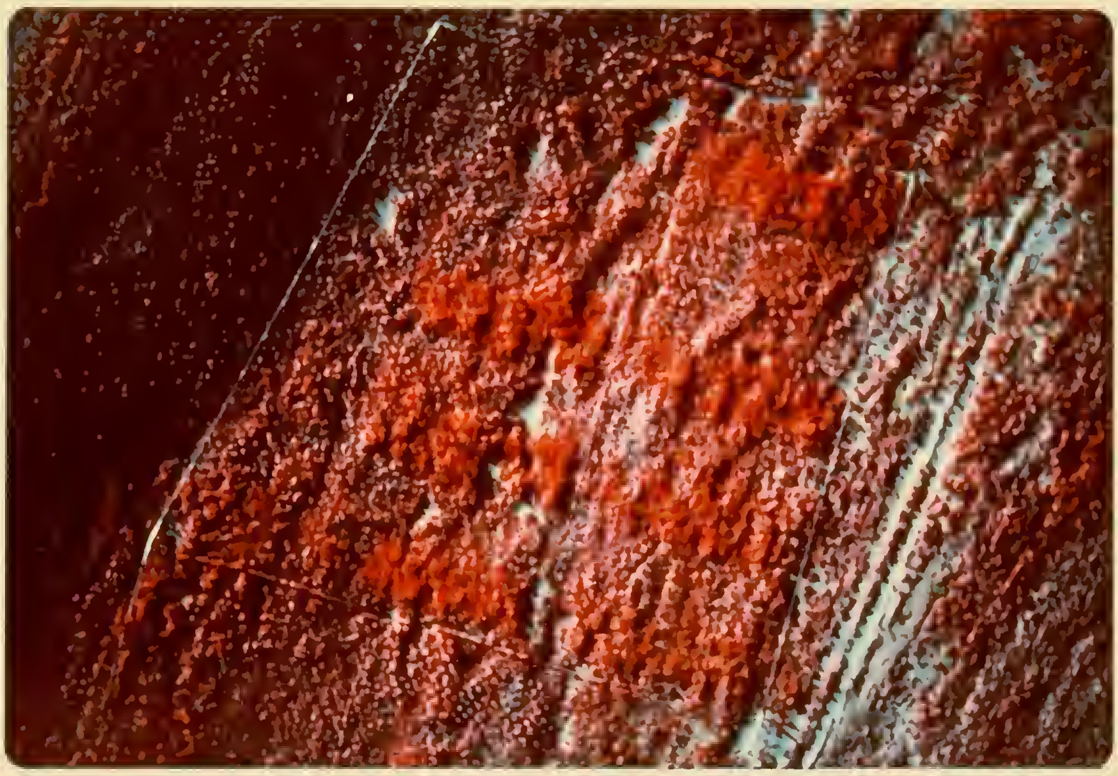

Figure 27. Aerial infra-red photograph of the fertilized plot at Colony showing vigorous growth on fertilized areas.

Soil compaction and topsoil contamination on the plot testing fertilization were variable. Even though fertilized and nonfertilized subplots were randomly distributed, a larger proportion of the fertilized subplots had adverse soil conditions. Therefore, the results are inconclusive and further testing is needed.

SEASON OF SEEDING

Compared to spring seeding, fall seeding resulted in a significant increase in plant vigor. Fall seeding enables the plant to take advantage of winter and early spring moisture. Fall seeded species excavated when the spring seeding was being done had germinated and, in some instances, begun growth.

CONCLUSIONS

The following conclusions concerning Bentonite reclamation were reached after two years of study.

1. Surface treatments did not produce significant differences in vegetative production or canopy cover. Besides failing to benefit the plants, surface treatments increased the possibility of topsoil contamination.
2. Seeding rates of 12 to 15 pounds per acre were sufficient to establish healthy stands. Decreases from this rate yielded significant decreases in canopy cover and production, while rate increases generated no significant increases.
3. While species selection should be tailored to the climate and soils of the individual site, several species grew consistently well on reclaimed bentonite pits. Nordan and Fairway crested wheatgrasses, and Thickspike wheatgrass produced good stands on all sites, while Pubescent, Western, and Streambank wheatgrasses were fairly successful on all as well. Basin and

Canadian wildryes, and Indian ricegrass, while not individually establishing good stands, should be utilized to increase plant diversity. Greasewood was the only shrub which grew consistently. Poor germination rather than a poor site appeared to be the main reason for shrub failure.

4. Fertilization of plants during the first spring of growth produced no significant difference in production or canopy cover.
5. Fall seedings yielded significantly more plant vigor than spring seedings.

RECOMMENDATIONS

A number of recommendations have been derived from this study. The recommendations fall into two categories: the first suggests improvements for ongoing reclamation, and the second, aids for improving reclamation through continued research. These recommendations are the result of reviewing the reclamation literature, past and present reclamation, and the results of this study.

Recommendations to improve reclamation include:

1. Burying the most toxic materials.
2. Exercising extreme care in topsoil salvage. While all suitable materials should be salvaged because of short supply, caution should be used to avoid contaminating the topsoil with undesirable or toxic materials.
3. Salvaging subsoils and redistributing them between the topsoil and the overburden. The highest quality soils material other than the overburden should be salvaged and then used as a buffer between the topsoil and the overburden.
4. Redistributing topsoil evenly. Typically vegetation grows and produces uniform stands only in sufficient topsoil.

5. Loosening the seedbed. While mixing of topsoil and overburden should be avoided, the seedbed must be loose. The soils inhibit root penetration under any circumstances, and an overly compacted seedbed only compounds the problem.
6. Selecting species to be reseeded with climate and soils in mind. The species that will thrive vary from area to area.
7. Seeding in the fall. This would enable plants to take advantage of all moisture from the winter and early spring, thus maximizing plant growth and reserves before going into the highest stress period, the summer.

It is recommended that the following procedures be researched to determine their value to bentonite mine reclamation.

1. The use of natural seed sources for species and varieties adapted to sodic and saline sites, particularly native forb and shrub species.
2. The use of ammendments such as gypsum or calcium chloride, with and without supplemental irrigation, to overcome the adverse qualities of the soils.
3. The use of mulch to mitigate the adverse physical qualities of the soils.
4. The use of containerized seedlings or on-site transplants to increase shrub propogation.

Funds from this grant which were not expended have been allocated for an additional year of plot monitoring. The results from this will be presented in supplemental reports prepared by the Department of State Lands, and will be available from the Old West Regional Commission.

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APPENDIX A

PHYSICAL PARAMETERS OF THE TEST SITES

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Table A-1. 1974 Precipitation Data

Climatological Data - Inches of Precipitation

1974	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Montana													
Glasgow	.18	.25	.93	.49	3.27	2.0	2.31	2.69	.07	.42	.26	.25	13.12
Albion[1]	.29	.06	.33	3.4	2.81	1.81	1.19	1.71	.42	1.33	.23	.20	13.78
Forsyth[2]	.16	.08	.45	1.47	3.42	1.47	.87	1.61	.35	.51	.65	.07	11.11
Wyoming													
Deaver[3]	.10	T	.21	.44	.44	.65	.40	.81	.29	.76	.27	T	4.37
Lovell[4]	.08	T	T	.15	.46	1.81	1.30	.73	.24	.95	.68	T	6.40
Greybull[4]	.48	.00	.10	.18	.68	.65	.30	.45	.66	.57	.80	.03	4.90
Colony	.06	.22	.58	2.38	2.05	1.06	2.51	.82	.67	1.34	.42	.11	12.22
Upton	.30	.19	T	.56	1.7	.50	1.54	2.06	.49	1.59	.08	.32	9.33

[1] Meteorological station nearest Alzada, Montana plot.

[2] Meteorological station nearest Vananda, Montana plot.

[3] Meteorological station nearest Warren, Montana plot.

[4] Meteorological station nearest Greybull, Wyoming plot.

Table A-2. 1975 Precipitation Data

Climatological Data - Inches of Precipitation

1975	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Montana													
Glasgow	.11	.23	.61	1.30	1.93	1.20	4.18	1.37	.42	1.77	.40	.38	13.90
Albion[1]	.65	.24	.70	2.44	4.86	3.72	1.04	.90	.05	.60	.18	.66	16.04
Forsyth[2]	1.14	.10	.43	2.98	3.36	2.56	4.05	-	-	-	-	-	-
Wyoming													
Deaver[3]	.59	.06	.15	1.11	1.34	.97	1.45	.12	.26	1.08	.10	T	7.23
Lovell[4]	.61	.10	.35	1.32	.73	.87	.83	.00	.15	1.52	.17	.07	6.72
Greybull[4]	3.42	.55	3.45	1.40	2.54	.88	.82	.06	T	1.42	.84	1.60	16.98
Colony	1.15	.38	.79	1.88	2.44	3.35	1.02	.81	.06	.67	.38	.73	13.66
Upton	.37	.37	.55	1.78	2.96	4.80	1.59	.66	.00	.63	.70	.45	14.86

[1] Meteorological station nearest Alzada, Montana plot.

[2] Meteorological station nearest Vananda, Montana plot.

[3] Meteorological station nearest Warren, Montana plot.

[4] Meteorological station nearest Greybull, Wyoming plot.

Table A-3. 1976 Precipitation Data

Climatological Data - Inches of Precipitation

1976	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Montana													
Glasgow	.27	.13	.30	.60	.64	4.27	5.00	1.16	.41	.21	.26	.28	13.53
Albion[1]	.15	.17	.38	2.45	2.32	6.33	3.72	.98	.45	.37	.12	.20	17.64
Forsyth[2]	.27	.43	.19	2.07	1.53	2.46	.22	.30	.52	1.08	.38	.23	9.68
Wyoming													
Deaver[3]	.09	.10	.03	1.08	.24	1.25	.16	1.36	.85	.20	.33	T	5.69
Lovell[4]	.10	.12	.06	1.33	.08	1.22	.12	1.75	1.05	.39	.40	.00	6.62
Greybull[4]	.35	.72	.14	.93	.44	3.69	.02	.71	1.02	.32	.97	.03	9.34
Colony	.31	.49	.55	1.97	1.45	7.54	1.79	1.15	.17	.52	.58	.19	16.71
Upton	.59	.50	.45	2.29	2.60	3.69	5.20	.60	.47	.60	1.08	.32	18.39

[1] Meteorological station nearest Alzada, Montana plot.

[2] Meteorological station nearest Vananda, Montana plot.

[3] Meteorological station nearest Warren, Montana plot.

[4] Meteorological station nearest Greybull, Montana plot.

ALZADA PLOT; ALZADA, MONTANA						September, 1975			Plot Sample Layout		1 2 3 4 5 6 7 8 9			
			ppm for soils % for plant		milli mhos	Meq/L for soils %	% for plants				Mechanical Analysis %			Notes
Lab #	Sample #	pH	P	K	Salt	O.M.	Ca	Mg	Na	SAR	Sand	Silt	Clay	
722	1	7.5	6	434	6.4	1.30	22.09	13.66	86.77	20.52	11.28	20.72	58.00	
716	2	7.0	16	434	4.6	1.82	24.98	10.29	87.87	20.92	14.00	32.00	54.00	
721	3	7.5	14	387	5.2	.95	11.72	7.10	76.88	25.06	13.64	26.36	60.00	
718	4	7.3	6	297	5.2	1.30	25.95	5.00	53.94	13.71	14.00	26.00	60.00	
714	5	7.0	24	324	6.4	1.75	27.89	12.15	37.66	8.41	16.00	28.00	56.00	
717	6	7.2	4	297	2.7	1.49	20.18	5.32	30.09	8.42	24.00	26.00	50.00	
719	7	7.0	24	351	6.1	1.43	24.01	11.39	92.27	21.93	17.64	26.36	56.00	
715	8	6.7	35	397	5.8	1.35	18.78	11.77	56.12	14.47	12.00	34.00	54.00	
720	9	7.3	9	369	4.9	1.01	23.05	13.66	93.38	21.79	13.64	26.36	60.00	
R713	Over-burden	6.6	78	626	8.9	2.30	21.13	13.66	106.63	25.56	20.00	30.00	50.00	
724	surface	7.5	9	236	8.2	.84	2.62	.67	4.08	3.18	29.28	28.72	32.00	

COLONY PLOT; COLONY, WYOMING

September 25, 1975

Plot Sample Layout

1 2 3
4 5 6
7 8 9

			ppm for soils % for plants		milli-mhos	Meg/L for soils % for plants (soluble)					Mechanical Analysis %			Notes
Lab #	Sample #	pH	P	K	Salt	O.M.	Ca	Mg	Na	SAR	Sand	Silt	Clay	
R686	1	6.9	40	342	4.0	1.68	18.28	9.57	48.50	12.99	17.28	28.00	54.72	
690	2	7.5	21	279	6.7	1.30	25.95	15.21	37.66	8.30	21.28	22.00	56.72	
688	3	8.0	26	315	2.6	1.62	13.58	5.49	108.85	30.25	19.28	24.72	56.00	
692	4	7.4	24	389	6.7	1.75	20.18	9.21	63.75	16.63	17.28	24.00	58.72	
695	5	7.5	21	297	7.3	1.35	23.05	13.66	43.07	10.05	21.28	22.00	56.72	
693	6	8.1	29	444	5.8	1.62	8.96	3.45	92.27	37.04	21.28	24.00	54.72	
687	7	7.2	24	297	4.6	1.12	21.13	10.66	38.74	9.71	21.28	26.00	52.72	
691	8	7.2	21	351	8.5	1.25	21.13	15.61	43.07	10.04	17.28	24.00	58.72	
689	9	7.5	24	315	4.0	1.06	26.91	13.28	32.25	7.19	21.28	24.00	54.72	
R1109	undis-turbed	8.9	24	294	3.7	.51	----	----	----	----	30.16	26.00	43.84	
694	Over-burden	8.3	16	522	5.2	1.68	13.58	4.42	67.03	22.34	15.28	22.00	62.72	

GREYBULL PLOT; GREYBULL, WYOMING

September 26, 1977

Plot Sample Layout

1 2 3
4 5 6
7 8 9

			ppm for soils % for plant		milli mhos	Meq/L for soils % for plants (Soluble)					Mechanical Analysis %			Notes
Lab #	Sample #	pH	P	K	Salt	O.M.	Ca	Mg	Na	SAR	Sand	Silt	Clay	
R1101	1	7.4	26	267	39.7	.84	21.00	193.40	538.71	52.03	24.16	32.72	43.12	
1112	2	7.3	24	285	30.2	.65	18.70	332.84	433.84	32.75	15.80	38.00	46.20	
1105	3	7.3	24	276	29.2	.90	23.29	271.00	406.36	33.49	24.16	40.36	35.48	
1113	4	7.4	35	239	18.7	1.01	23.29	49.23	134.25	22.27	23.80	58.00	18.20	
1110	6	7.6	40	285	18.7	.95	23.29	89.29	253.38	33.77	22.16	44.00	33.84	
1114	7	6.9	40	186	15.4	.95	23.29	83.18	166.65	22.84	23.80	40.00	36.20	
1111	9	7.5	46	221	14.8	.90	25.57	29.46	101.94	19.43	32.16	34.00	33.84	
1107	Over-burden	7.4	21	389	18.7	.30	23.29	58.97	258.82	40.35	24.16	32.00	43.84	

UPTON PLOT; UPTON, WYOMING	September 28, 1975	Plot Sample Layout	1 2 3 4 5 6 7 8 9

			ppm for soils % for plant		milli mhos	Meg for soils % % for plants					Mechanical Analysis %			Notes
Lab #	Sample #	pH	P	K	Salt	O.M.	Ca	Mg	Na	SAR	Sand	Silt	Clay	
698	1	7.8	35	193	2.9	1.89	26.91	20.94	----	----	40.72	28.72	30.56	
702	2	8.0	29	142	1.3	1.89	10.80	6.97	11.22	3.76	44.36	24.36	31.28	
699	3	8.1	26	167	2.4	1.25	15.45	10.66	17.35	4.80	38.72	24.36	36.92	
700	4	8.1	37	201	2.2	1.62	16.39	13.66	26.85	6.92	38.72	28.36	32.92	
705	5	8.2	29	167	1.1	2.05	4.41	3.14	11.44	5.88	40.36	30.36	29.28	
701	6	8.4	21	167	1.6	1.43	7.13	4.54	12.97	5.36	40.36	24.36	37.28	
R696	7	8.4	19	159	2.2	1.35	9.87	6.44	97.79	34.24	39.28	22.00	38.72	
703	8	8.0	29	159	1.6	1.97	6.22	4.47	12.97	5.61	44.36	26.36	29.28	
697	9	8.2	26	125	.9	2.05	3.52	2.57	44.16	25.30	37.44	34.00	28.56	
704	Over-burden	8.1	43	218	4.0	1.06	22.09	12.90	----	----	34.36	22.36	43.28	
710	Surface	6.8	35	92	0.2	1.75	1.73	.84	2.79	2.46	52.00	30.00	18.00	

VANANDA PLOT; VANANDA, MONTANA

June 2, 1976

Plot Sample Layout

1 2 3
4 5 6
7 8 9

			ppm for soils % for plant		milli mhos	Meg/L for soils % for plants (soluble)					Mechanical Analysis %			Notes
Lab #	Sample #	pH	P	K	Salt	O.M.	Ca	Mg	Na	SAR	Sand	Silt	Clay	
37	1	7.6	71	305	7.2		23.56	6.43	86.25	22.27	22.00	30.72	47.28	
38	2	7.7	64	251	13		23.56	12.89	151.61	35.51	18.00	25.08	56.92	
39	3	6.6	49	223	17		28.20	25.08	217.99	42.23	16.00	19.44	64.56	
40	7	7.8	68	332	11		28.20	7.35	128.91	30.57	19.64	29.44	50.92	
41	8	8.2	64	232	18		28.20	16.62	234.21	49.47	16.00	21.08	62.92	
42	9	8.0	64	251	14		23.56	14.75	186.66	42.64	20.00	21.44	58.56	
43	Over-burden	7.1	103	213	19		28.20	37.57	283.34	49.40	18.00	21.44	60.56	

WARREN PLOT; WARREN, MONTANA						September 26, 1975		Plot Sample Layout		1 2 3 4 5 6 7 8 9				
			ppm for soils % for plants		milli mhos	Meq/L for soils % for plants (soluble)					Mechanical Analysis %			Notes
Lab #	Sample #	pH	P	K	Salt	O.M.	Ca	Mg	Na	SAR	Sand	Silt	Clay	
1106	1	7.7	40	248	15.7	.90	21.00	3.69	247.95	70.56	14.16	30.00	55.84	
1104	2	7.6	55	322	11.2	.77	21.00	2.15	188.28	55.34	16.16	30.36	53.48	
1108	3	7.4	11	257	14.5	.84	18.70	8.45	269.70	73.19	8.16	42.00	49.84	
R1100	7	7.8	14	248	11.2	.65	21.00	2.15	188.28	55.34	28.16	26.00	45.84	
1103	9	7.3	26	239	12.1	.44	23.29	2.92	247.95	68.49	12.16	32.36	55.48	
1102	Over-burden	7.4	24	248	18.4	.71	21.00	11.74	442.84	109.45	8.16	30.36	61.48	

APPENDIX B

EXPERIMENTAL TEST RESULTS

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Table B-1. Summary of Surface Treatment Results

		Canopy Cover in Percent	Density st/m^2	Production g/m^2
Pubescent wheatgrass	CONTROL	6.22	30.41	14.86
	FURROWED	12.76	31.45	14.03
	GOUGED	8.03	21.96	10.98
Western wheatgrass	CONTROL	15.35	35.22	10.53
	FURROWED	10.78	32.00	10.85
	GOUGED	14.94	42.23	15.76
Streambank wheatgrass	CONTROL	16.55	70.00	11.05
	FURROWED	21.97	86.32	13.90
	GOUGED	17.95	98.06	14.96
Thickspike wheatgrass	CONTROL	23.25	64.45	16.46
	FURROWED	25.10	101.49	22.13
	GOUGED	18.89	83.27	20.53
Fairway crested wheatgrass	CONTROL	19.25	58.63	15.51
	FURROWED	21.80	70.07	22.62
	GOUGED	30.28	88.54	29.33
Nordan crested wheatgrass	CONTROL	20.08	133.48	22.66
	FURROWED	21.78	75.35	32.00
	GOUGED	22.39	130.89	37.70
Canadian wildrye	CONTROL	7.29	9.83	3.08
	FURROWED	4.77	11.38	4.50
	GOUGED	7.50	11.95	5.89

Table B-1. (cont.)

		Canopy Cover in Percent	Density st/m^2	Production g/m^2
Basin wildrye	CONTROL	3.08	7.08	0.27
	FURROWED	5.14	9.72	3.82
	GOUGED	3.76	6.88	1.36
Indian ricegrass	CONTROL	3.62	1.72	0.60
	FURROWED	3.46	15.93	1.85
	GOUGED	1.57	0.54	0.10
Yellow sweet clover	CONTROL	16.85	2.90	
	FURROWED	17.01	2.25	
	GOUGED	23.77	4.31	
Greasewood	CONTROL	3.9		
	FURROWED	5.5		
	GOUGED	7.9		
Buffalo grass*	CONTROL	1.0		
	FURROWED	0		
	GOUGED	1.33		
Fourwing saltbush*	CONTROL	2.88		
	FURROWED	3.59		
	GOUGED	1.72		
Nuttall's saltbush*	CONTROL	0.53		
	FURROWED	0		
	GOUGED	0.17		
White prairie clover*	CONTROL	0.28		
	FURROWED	0.34		
	GOUGED	0.23		

Table B-1. (cont.)

		Canopy Cover in Percent	Density st/m^2	Production g/m^2
Big sage	CONTROL			
	FURROWED			
	GOUGED			
Squirreltail[+]	CONTROL			
	FURROWED			
	GOUGED			
Siberian wheatgrass	CONTROL		28.34	
	FURROWED		26.45	
	GOUGED		26.27	

[*] only grew at Upton site

[+] only planted at Upton site

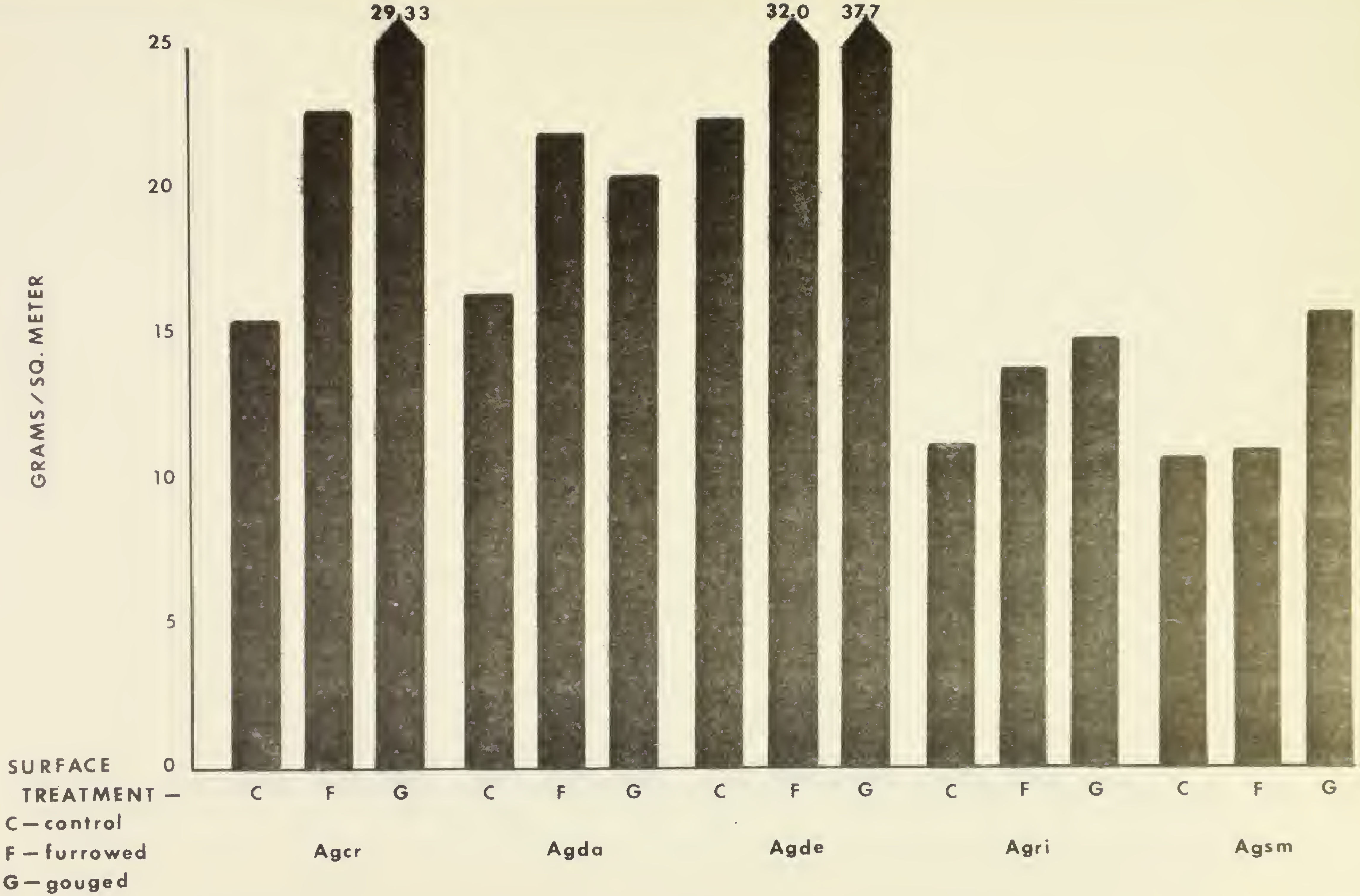

Figure B-1. Surface Treatment: Summary of Production Results

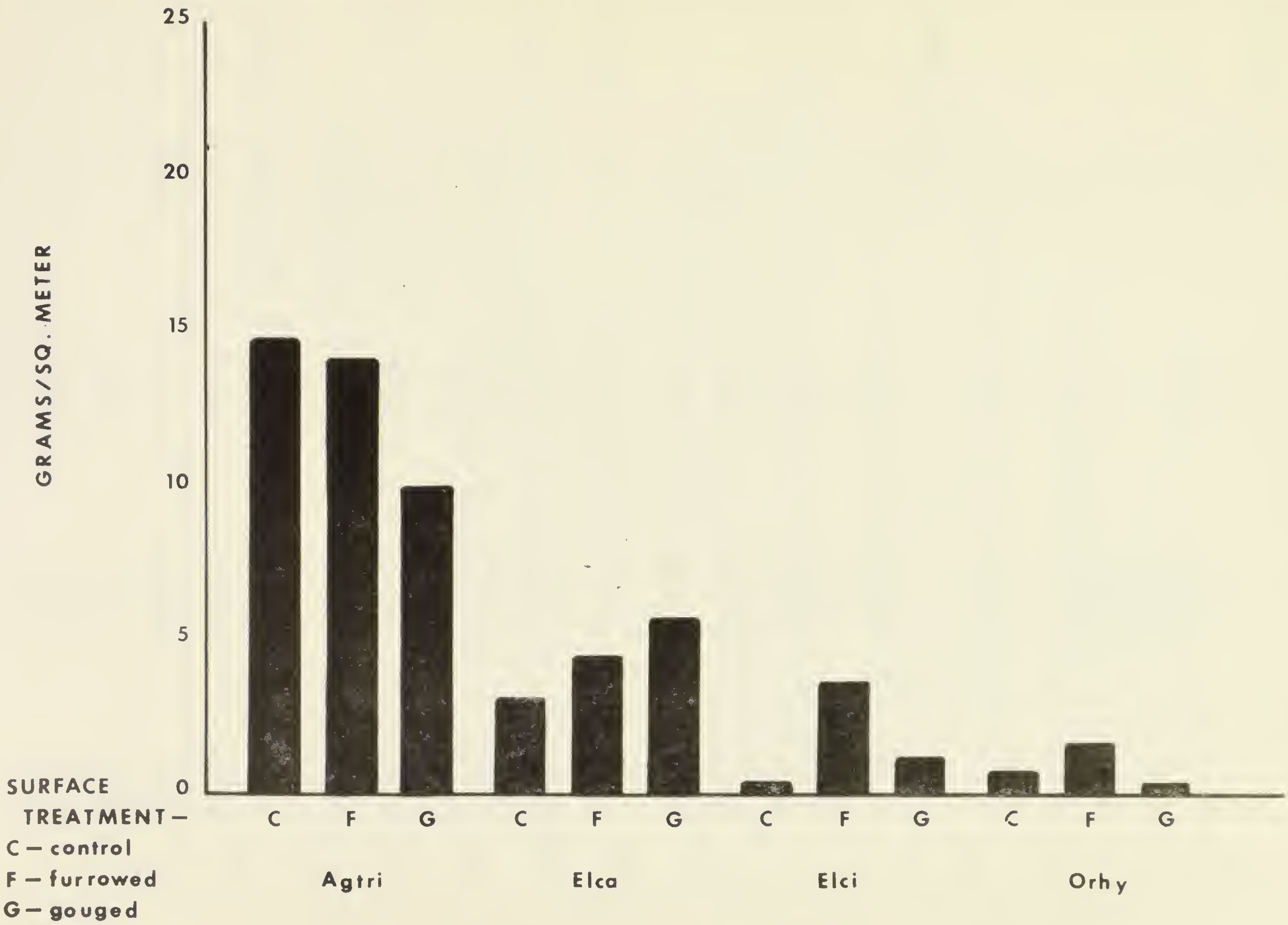

FIGURE B-1. (CONT.) SURFACE TREATMENT: SUMMARY OF PRODUCTION RESULTS

Table B-2. Summary of Seeding Rate Results

		Canopy Cover in %	Density st/m^2	Production g/m^2
Mixture	ACU-1			
	2 X[1/]	21.40	84.33	17.18
	1.5 X	19.56	76.32	12.79
	1 X	19.39	82.29	12.44
	.75 X	17.90	56.00	10.80
	.5 X	15.67	64.03	8.32
Mixture	ACU-2			
	2 X	28.60	147.65	19.66
	1.5 X	23.08	101.91	19.38
	1 X	25.55	103.38	19.26
	.75 X	10.65	46.29	8.62
	.5 X	17.13	57.45	9.74
Mixture	RP-1			
	2 X	19.78	70.76	11.78
	1.5 X	20.63	67.47	10.67
	1 X	20.78	62.79	12.23
	.75 X	16.40	52.43	9.83
	.5 X	16.23	44.23	8.81
Mixture	GV-1			
	2 X	62.81	139.70	9.24
	1.5 X	53.13	162.00	4.98
	1 X	58.44	99.00	8.69
	.75 X	41.88	57.10	4.38
	.5 X	50.00	72.10	7.40

[1/] Multiple of the recommended seeding rate

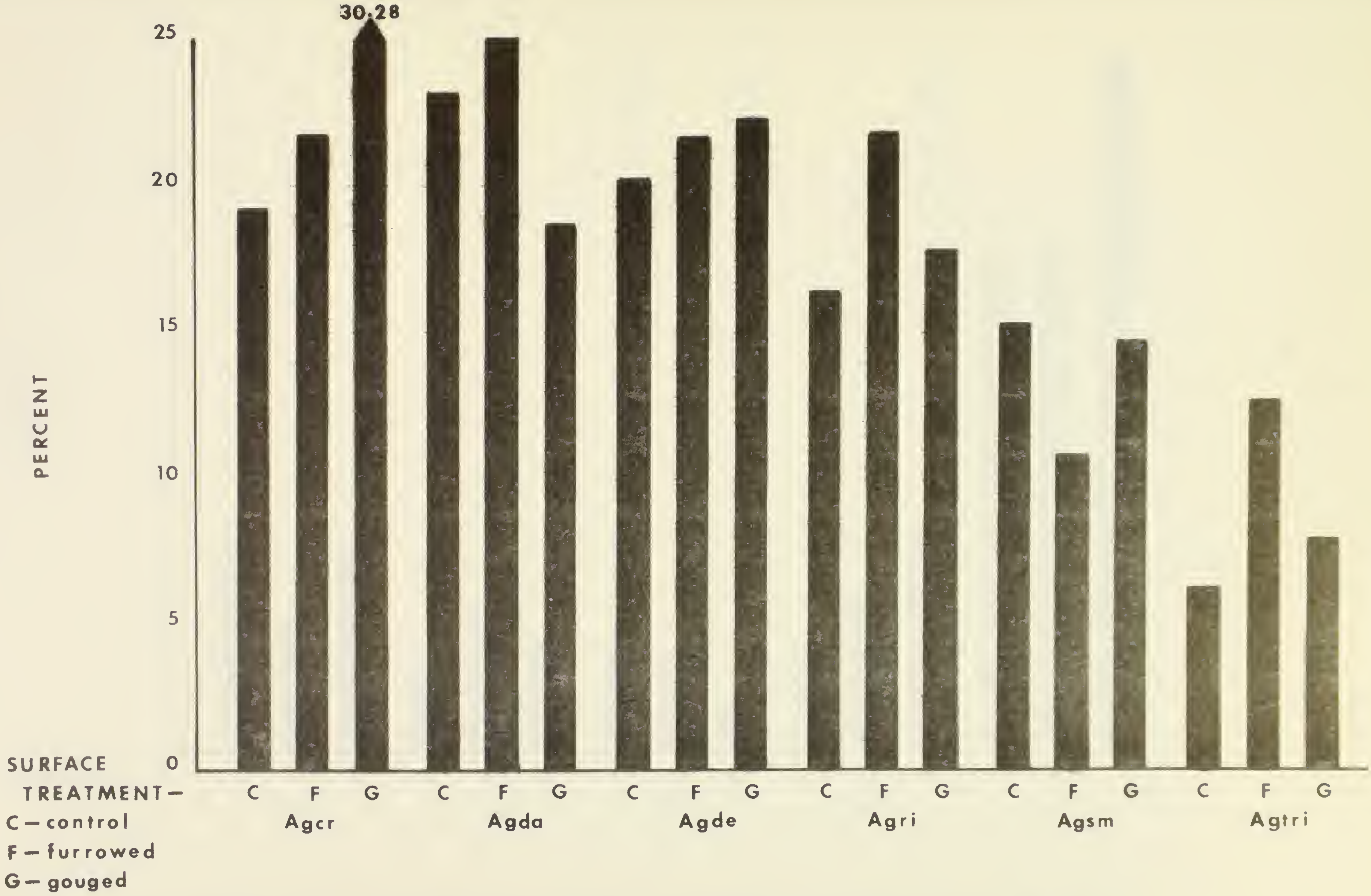

FIGURE B-2. SURFACE TREATMENT: SUMMARY OF CANOPY COVER RESULTS

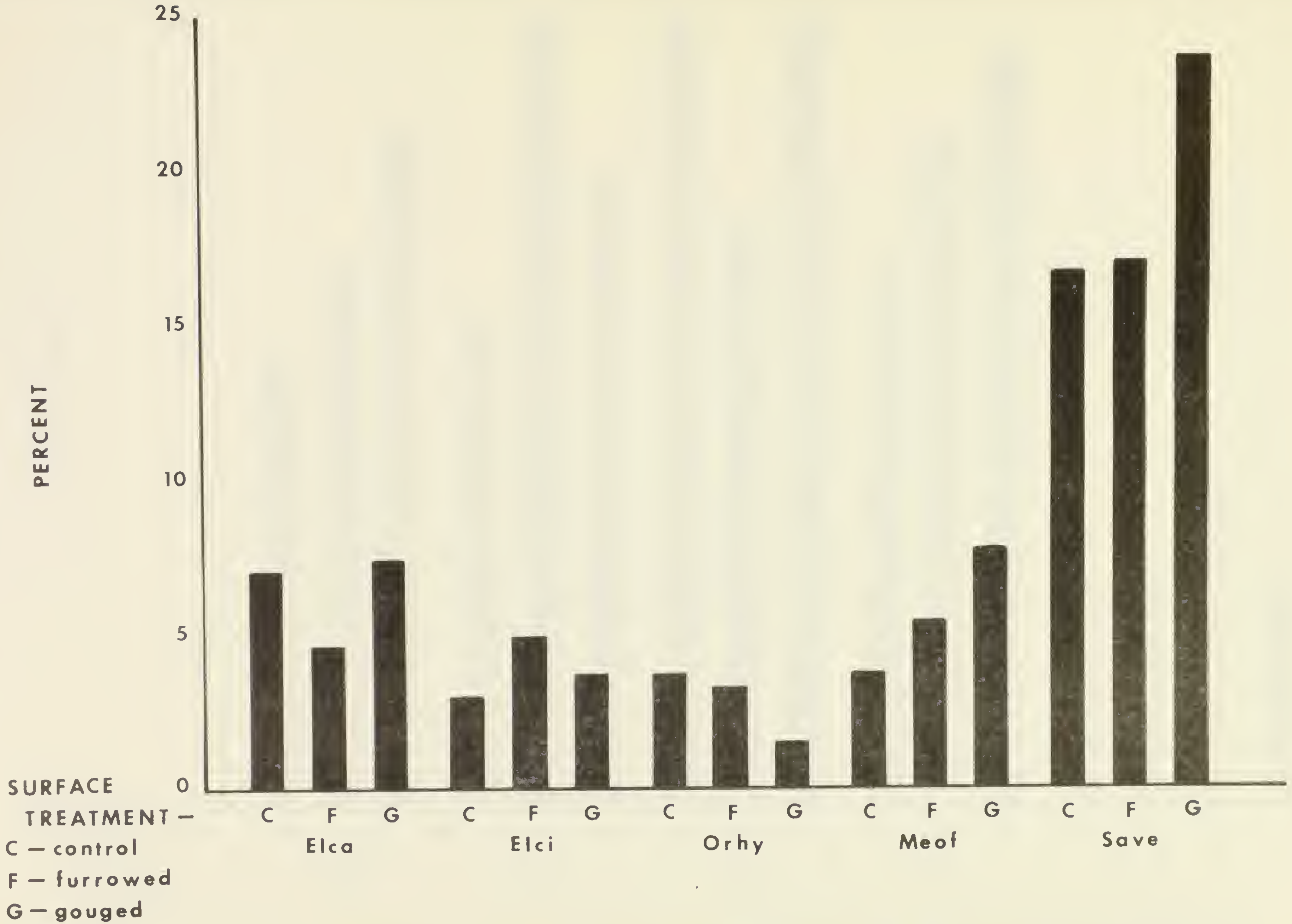

FIGURE B-2. (CONT.) SURFACE TREATMENT: SUMMARY OF CANOPY COVER RESULTS

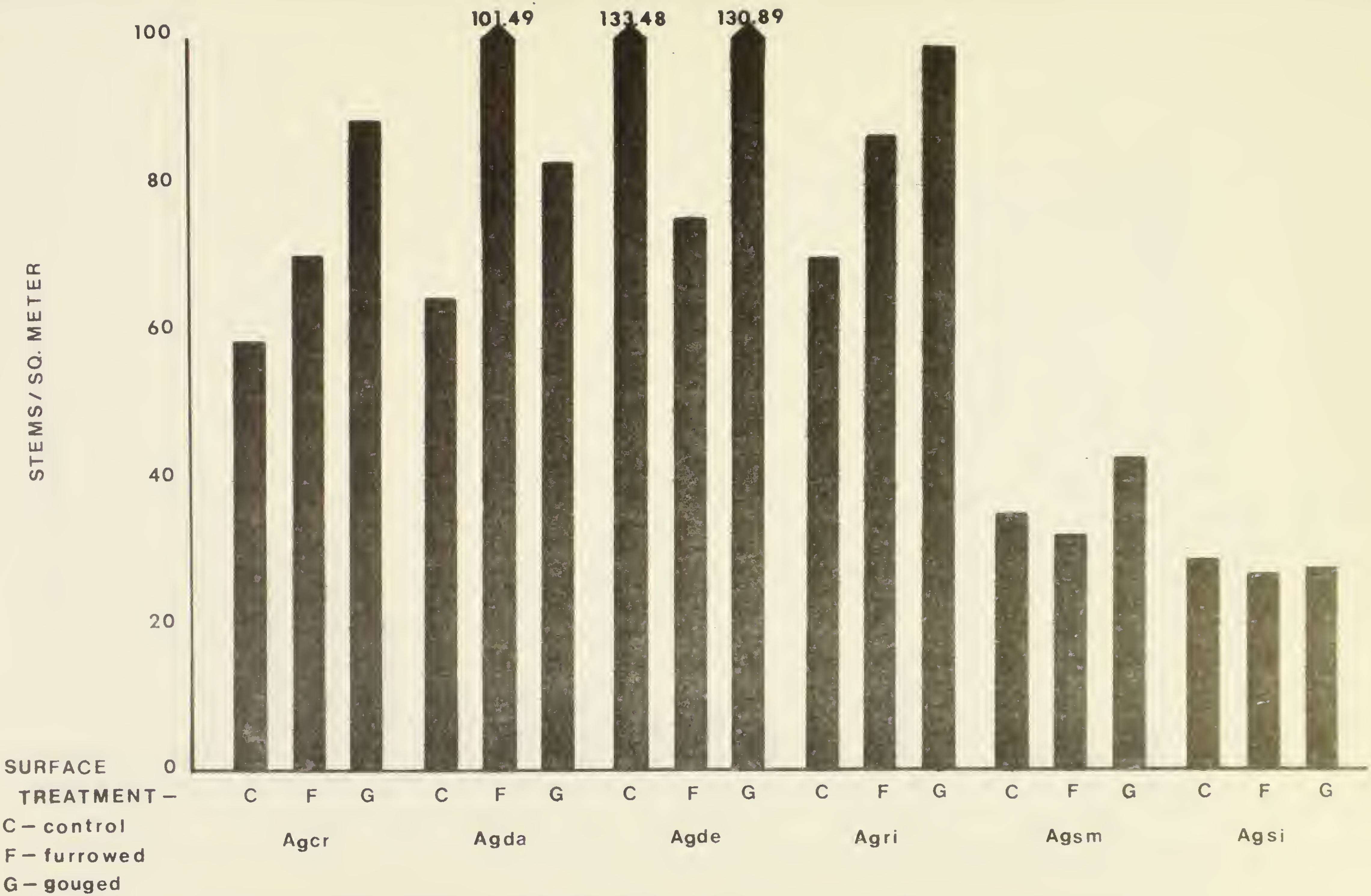

FIGURE B-3. SURFACE TREATMENT: SUMMARY OF DENSITY RESULTS

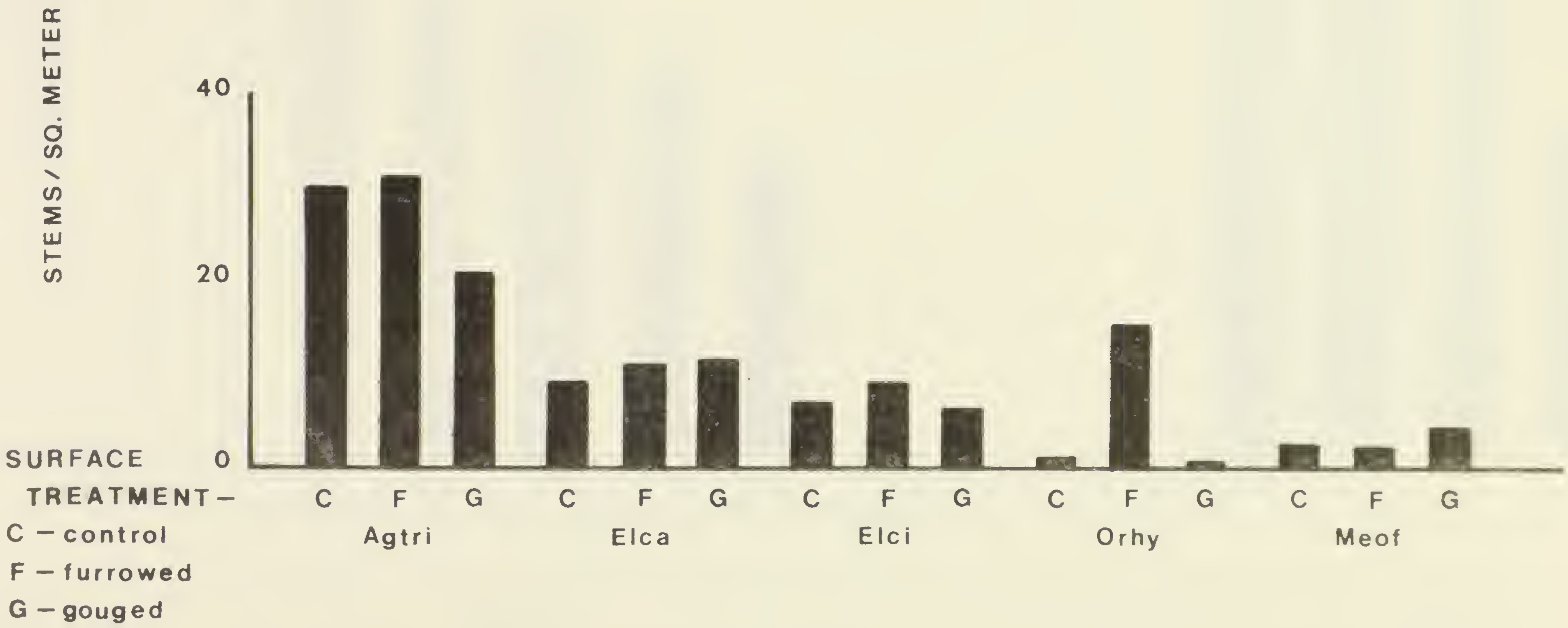

FIGURE B-3. (CONT.) SURFACE TREATMENT: SUMMARY OF DENSITY RESULTS

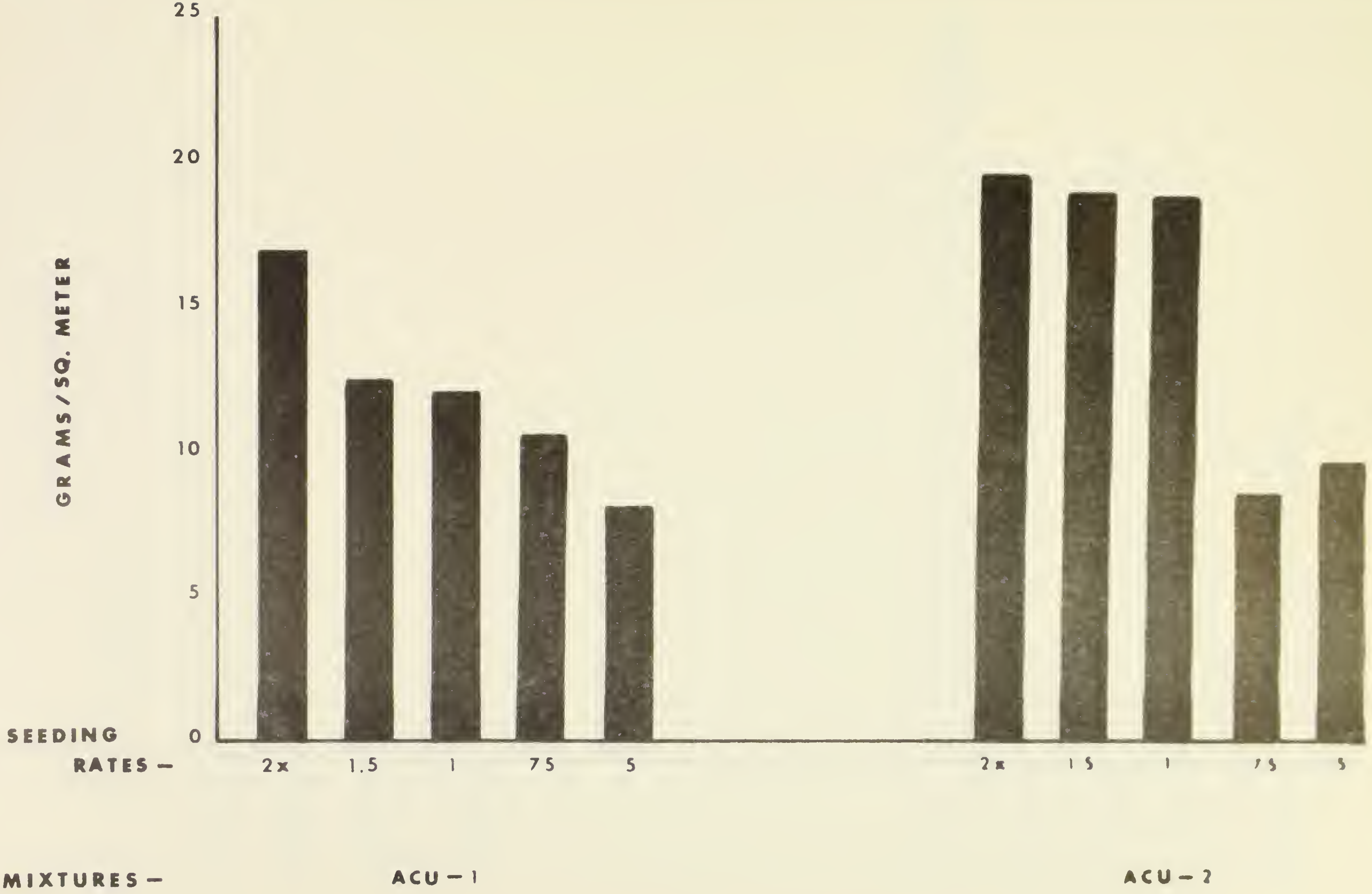

FIGURE B-4. SEEDING RATE: SUMMARY OF PRODUCTION RESULTS

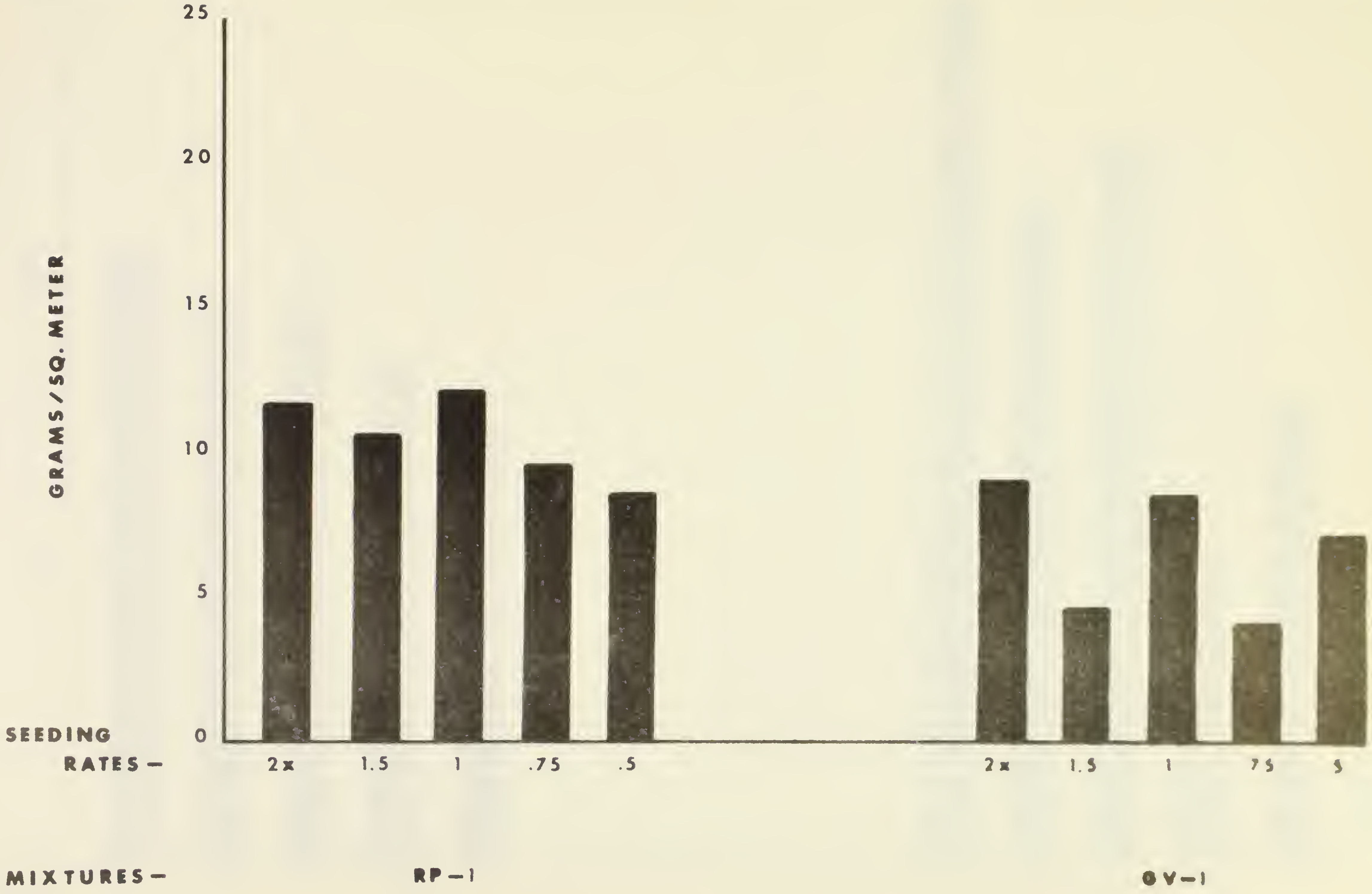

FIGURE B-4. (CONT.) SEEDING RATE: SUMMARY OF PRODUCTION RESULTS

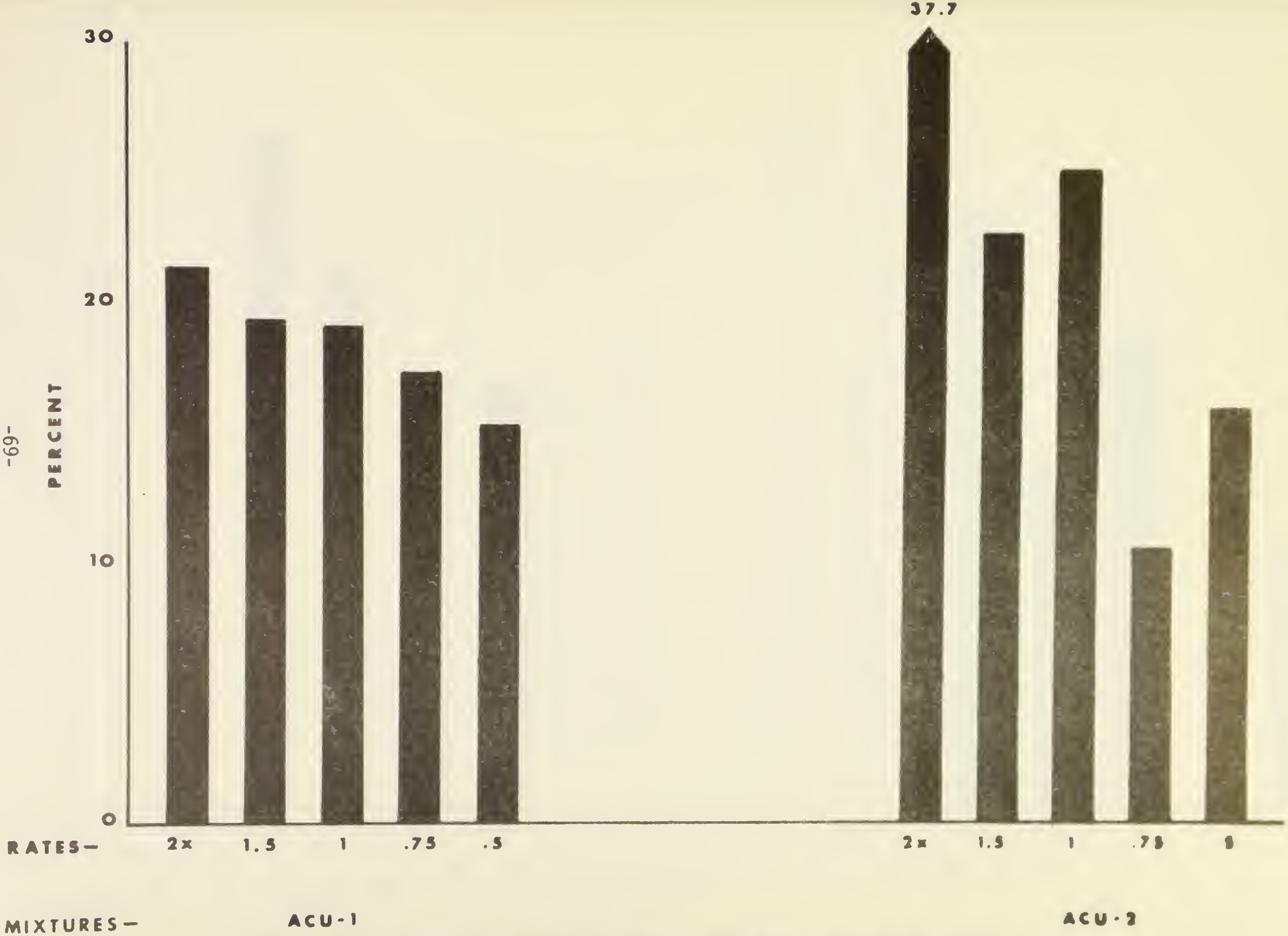

FIGURE B-5. SEEDING RATE: SUMMARY OF CANOPY COVER RESULTS

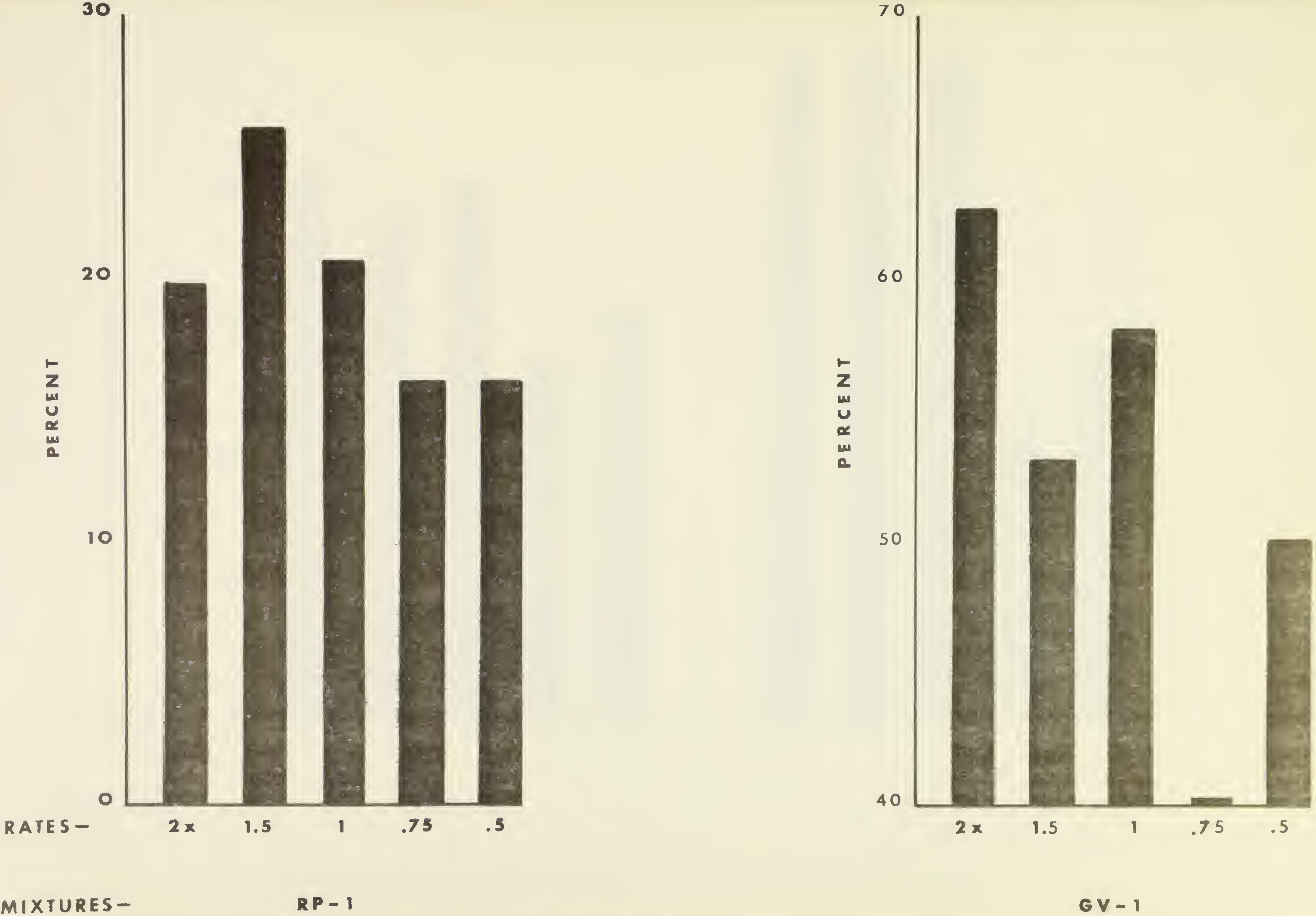

FIGURE B-5. (CONT.) SEEDING RATE: SUMMARY OF CANOPY COVER RESULTS

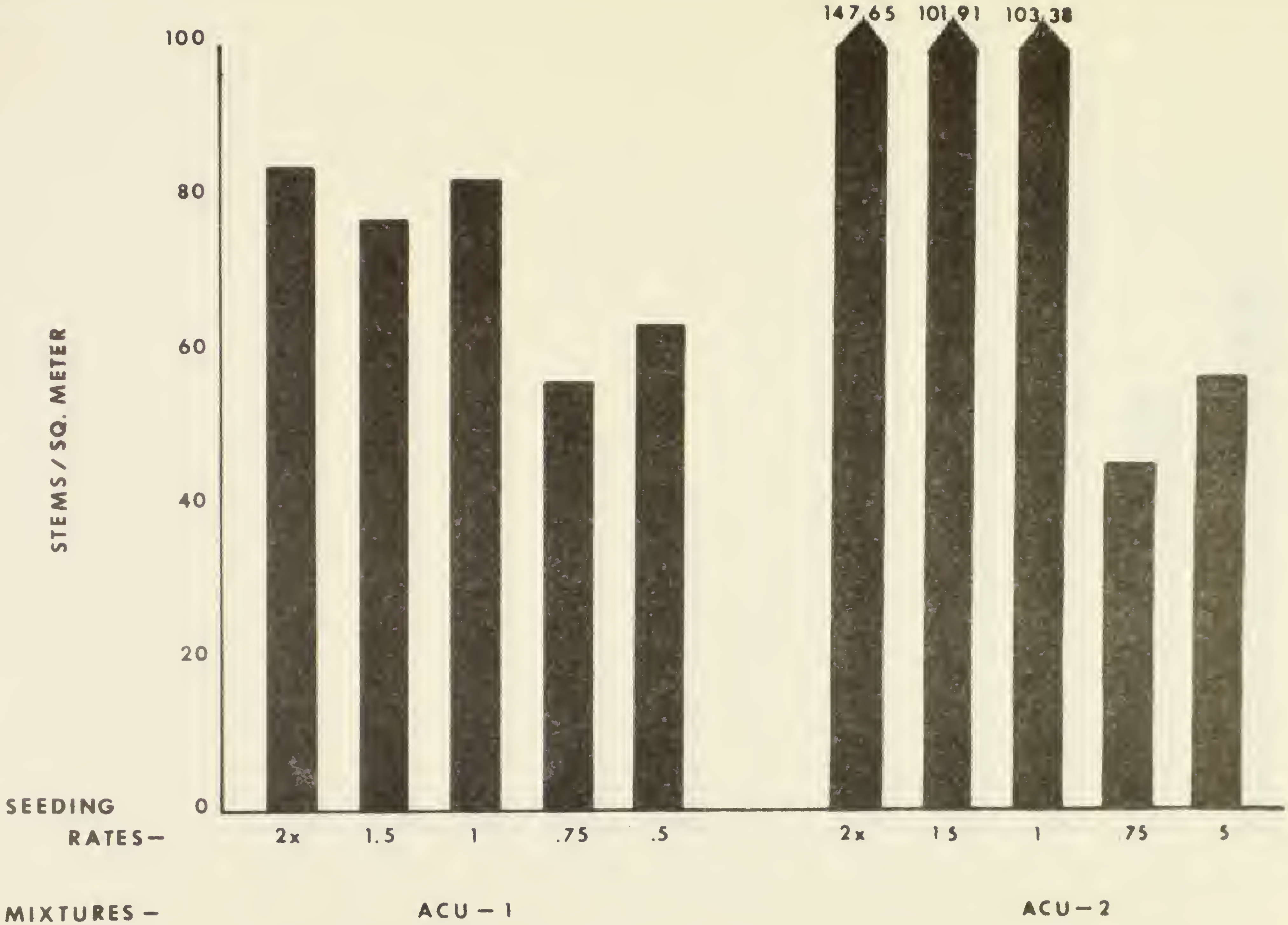

FIGURE B-6. SEEDING RATE: SUMMARY OF DENSITY RESULTS

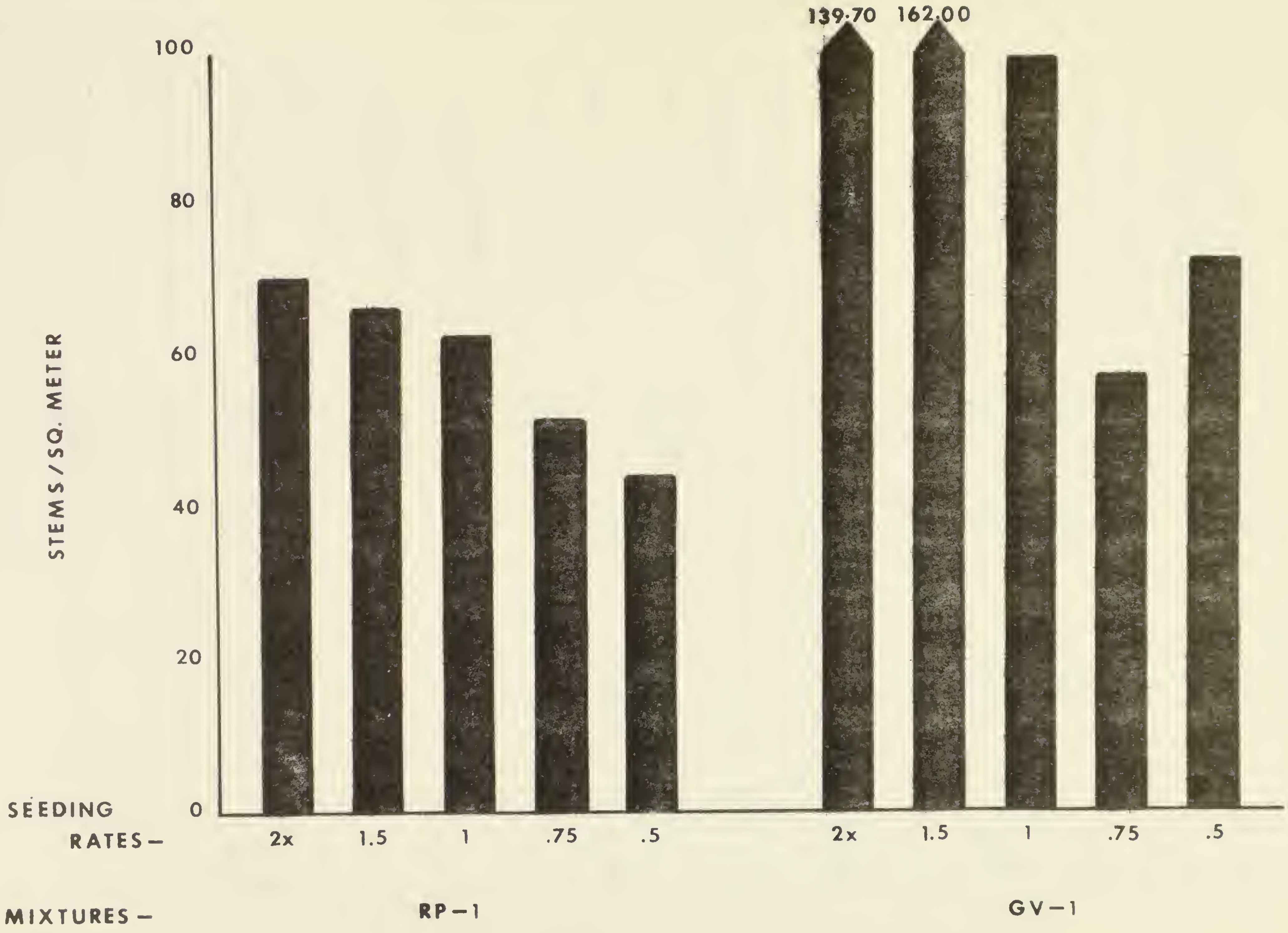

FIGURE B-6. (CONT.) SEEDING RATE: SUMMARY OF DENSITY RESULTS

Table B-3. Alzada Site: Production Results

Species	TREATMENT	Production grams/meter^2		
		Control	Furrowed	Gouged
Fairway crested wheatgrass		17.58	7.24	26.03
Thickspike wheatgrass		10.0	0.83	8.28
Nordan crested wheatgrass		12.45	8.19	6.50
Streambank wheatgrass	Spring	2.16	1.64	2.67
	Fall	3.36	12.55	8.19
Western wheatgrass	Spring	6.17	5.95	14.62
	Fall	5.47	1.90	3.65
Siberian wheatgrass	Spring			
	Fall			
Pubescent wheatgrass	Spring	2.16	0.86	0.26
	Fall	0	0.04	1.16
Buffalo grass				
Canadian wildrye				
Basin wildrye	Spring			
	Fall			
Indian ricegrass		0.31	0.22	0.09
Big sage	Spring			
	Fall			
Fourwing saltbush	Spring			
	Fall			
Nuttalls saltbush	Spring			
	Fall			
Rubber rabbitbrush	Spring			
	Fall			
Yellow sweet clover	Spring	2.5	1.72	0.09
	Fall	0.6	0	3.33
White prairie clover	Spring			
	Fall			
Greasewood	Spring			
	Fall			

Table B-4. Alzada Site: Canopy Cover Results

Canopy Cover in percent

Species	TREATMENT	Control	Furrowed	Gouged
Fairway crested wheatgrass		11.25	9.0	18.75
Thickspike wheatgrass		8.12	8.13	8.75
Nordan crested wheatgrass		9.37	8.12	13.88
Streambank wheatgrass	Spring	3.25	1.88	4.38
	Fall	6.25	11.87	10.62
Western wheatgrass	Spring	7.5	1.25	3.13
	Fall	10.0	4.5	2.05
Siberian wheatgrass	Spring	.5	.625	3.75
	Fall	.05	.625	8.8
Pubescent wheatgrass	Spring	1.63		1.13
	Fall	2.62	.675	5.25
Buffalo grass				
Canadian wildrye		0.25		.625
Basin wildrye	Spring	0.125		
	Fall			.05
Indian ricegrass		0.175	0.175	.25
Big sage	Spring			
	Fall			
Fourwing saltbush	Spring			
	Fall			
Nuttalls saltbush	Spring			
	Fall			
Rubber rabbitbrush	Spring			
	Fall			
Yellow sweet clover	Spring	3.13	8.75	.875
	Fall	0.75	5.68	4.25
White prairie clover	Spring			
	Fall			
Greasewood	Spring	0.25		
	Fall	0.25	1.25	2.5

Table B-5. Alzada Site: Density Results

Species	TREATMENT	Density-Stems/meter^2 Control	Furrowed	Gouged
Fairway crested wheatgrass		23.68	38.54	36.60
Thickspike wheatgrass		13.24	30.14	19.27
Nordan crested wheatgrass		23.90	24.33	17.44
Streambank wheatgrass	Spring	9.69	5.92	11.73
	Fall	8.07	25.30	24.97
Western wheatgrass	Spring	18.30	1.61	16.04
	Fall	21.64	10.12	4.84
Siberian wheatgrass	Spring	1.07	1.29	4.31
	Fall	0.32	1.61	9.90
Pubescent wheatgrass	Spring	5.27	0	1.40
	Fall	3.01	3.66	9.04
Buffalo grass		0	0	0
Canadian wildrye		.11	0	.54
Basin wildrye	Spring	0.54	0	0
	Fall	0	0	.43
Indian ricegrass		1.18	1.29	0.32
Big sage	Spring	0	0	0
	Fall	0	0	0
Fourwing saltbush	Spring	0	0	0
	Fall	0	0	0
Nuttalls saltbush	Spring	0	0	0
	Fall	0	0	0
Rubber rabbitbrush	Spring	0	0	0
	Fall	0	0	0
Yellow sweet clover	Spring	0.43	1.29	0.65
	Fall	0.65	0.65	1.08
White prairie clover	Spring	0	0	0
	Fall	0	0	0
Greasewood	Spring	1.18	0.32	1.29
	Fall	0.22	0	0

Table B-6. Colony Site: Production Results

Species	TREATMENT	Production-grams/meter^2		
		Control	Furrowed	Gouged
Fairway crested wheatgrass		31.72	34.22	51.72
Thickspike wheatgrass		43.5	29.79	27.80
Nordan crested wheatgrass		38.67	39.71	38.24
Streambank wheatgrass	Spring	2.41	17.12	4.57
	Fall	12.46	5.95	20.52
Western wheatgrass	Spring	8.53	6.34	0.66
	Fall	14.74	23.24	9.40
Siberian wheatgrass	Spring			
	Fall			
Pubescent wheatgrass	Spring	14.22	21.21	0.74
	Fall	24.79	15.69	20.48
Buffalo grass				
Canadian wildrye		1.95	0.22	0.91
Basin wildrye	Spring			
	Fall	0.10	2.84	4.05
Indian ricegrass		1.0	1.72	0
Big sage	Spring			
	Fall			
Fourwing saltbush	Spring			
	Fall			
Nuttalls saltbush	Spring			
	Fall			
Rubber rabbitbrush	Spring			
	Fall			
Yellow sweet clover	Spring			
	Fall			
White prairie clover	Spring			
	Fall			
Greasewood	Spring			
	Fall			

Table B-7. Colony Site: Canopy Cover Results

Species	TREATMENT	Canopy Cover in percent		
		Control	Furrowed	Gouged
Fairway crested wheatgrass		36.25	36.25	47.5
Thickspike wheatgrass		31.5	38.75	23.75
Nordan crested wheatgrass		35.0	30.0	53.75
Streambank wheatgrass	Spring	5.50	16.75	9.0
	Fall	27.63	37.5	28.13
Western wheatgrass	Spring	10.13	9.0	1.0
	Fall	21.25	19.25	17.75
Siberian wheatgrass	Spring			
	Fall			
Pubescent wheatgrass	Spring	10.25	4.38	2.5
	Fall	19.25	33.75	22.5
Buffalo grass				
Canadian wildrye		0.5	1.88	2.5
Basin wildrye	Spring	0.25	0.75	0
	Fall	2.0	6.75	11.25
Indian ricegrass		0.5	2.50	
Big sage	Spring			
	Fall			
Fourwing saltbush	Spring			
	Fall			
Nuttalls saltbush	Spring			
	Fall			
Rubber rabbitbrush	Spring			
	Fall			
Yellow sweet clover	Spring			
	Fall			
White prairie clover	Spring			
	Fall			
Greasewood	Spring			
	Fall			0.5

Table B-8. Colony Site: Density Results

Density-Stems/meter^2

Species		TREATMENT		
		Control	Furrowed	Gouged
Fairway crested wheatgrass		155.44	114.64	238.54
Thickspike wheatgrass		79.87	169.87	157.59
Nordan crested wheatgrass		133.48	75.35	130.89
Streambank wheatgrass	Spring	34.45	39.18	42.63
	Fall	84.82	127.13	212.7
Western wheatgrass	Spring	33.69	35.52	5.71
	Fall	68.89	82.99	89.23
Siberian wheatgrass	Spring			
	Fall			
Pubescent wheatgrass	Spring	21.21	6.89	5.71
	Fall	61.57	63.08	31.11
Buffalo grass				
Canadian wildrye		2.15	12.49	5.17
Basin wildrye	Spring	0.54	2.15	0
	Fall	6.67	9.26	19.38
Indian ricegrass		1.72	15.93	0.54
Big sage	Spring			
	Fall			
Fourwing saltbush	Spring			
	Fall			
Nuttalls saltbush	Spring			
	Fall			
Rubber rabbitbrush	Spring			
	Fall			
Yellow sweetclover	Spring			
	Fall			
White prairie clover	Spring			
	Fall			
Greasewood	Spring			
	Fall			0.22

Table B-9. Glasgow Site: Production Results

Species	TREATMENT	Production-grams/meter^2		
		Control	Furrowed	Gouged
Fairway	Spring	1.43	4.18	1.64
	Fall	22.41	14.16	29.19
Thickspike	Spring	9.06	0	5.68
	Fall	32.11	24.17	21.55
Nordan	Spring	0.34	0	5.11
	Fall	6.93	11.83	13.02
Streambank	Spring	7.56	2.37	3.96
	Fall	10.15	17.03	38.36
Western	Spring	5.68	1.72	7.74
	Fall	10.61	7.91	27.74
Pubescent	Spring	2.46	0.95	2.81
	Fall	5.38	18.06	32.46
Buffalo grass	Spring	0	0	0
	Fall	0	0	0
Canadian wildrye	Spring	0	0	0
	Fall	0	0	0
Basin wildrye	Spring	0	12.99	5.11
	Fall	0	0	0
Indian ricegrass	Spring	0	0	0
	Fall	1.89	4.78	0
White prairie clover		0	0	0
Big sage Fourwing saltbush Nuttalls saltbush Rubber rabbitbrush	SHRUBS NOT CLIPPED			
Greasewood	Spring	0	0	0
	Fall	0	0	0

Table B-10. Glasgow Site: Canopy Cover Results

Species	TREATMENT	Canopy Cover in percent		
		Control	Furrowed	Gouged
Fairway	Spring	4.5	6.0	4.67
	Fall	36.83	23.75	35.0
Thickspike	Spring	15.0	3.38	5.0
	Fall	36.67	46.25	38.33
Nordan	Spring	2.5	2.0	6.67
	Fall	23.5	28.75	30.83
Streambank	Spring	17.0	5.25	10.0
	Fall	40.0	46.25	50.0
Western	Spring	6.67	4.13	12.5
	Fall	28.5	14.38	43.33
Siberian	Spring			
	Fall			
Pubescent	Spring	5.0	3.0	3.50
	Fall	16.67	31.25	20.0
Buffalo grass	Spring			
	Fall			
Canandian wildrye	Spring			
	Fall			
Basin wildrye	Spring			
	Fall	16.67	23.13	25.0
Indian ricegrass	Spring	3.33		
	Fall	17.5	13.13	5.83
Big sage				
Fourwing saltbush				
Nuttalls Saltbush				
Rubber rabbitbrush				
Yellow sweet clover	Spring		12.5	33.3
	Fall	50.0	46.08	75.0
White prairie clover				
Greasewood	Spring			
	Fall			

Table B-11. Glasgow Site: Density Results

Species	TREATMENT	Density-Stems/meter^2		
		Control	Furrowed	Gouged
Fairway	Spring	21.95	24.8	24.4
	Fall	77.2	70	61.03
Thickspike	Spring	70.5	12.9	25.8
	Fall	79.1	154.5	105.5
Nordan	Spring	14.96	8.6	37.4
	Fall	30.7	67.6	83.96
Streambank	Spring	78.3	20.1	40.2
	Fall	101.9	141.6	174.4
Western	Spring	16.9	14.96	37.4
	Fall	39.2	16.6	30.6
Siberian	Spring			
	Fall			
Pubescent	Spring	7.21	7.5	19.4
	Fall	19.9	52.9	27.23
Buffalo grass	Spring			
	Fall			
Canadian wildrye	Spring			
	Fall			
Basin wildrye	Spring			
	Fall	25.8	32.9	20.1
Indian ricegrass	Spring			
	Fall	13.0	7.5	6.0
Big sage				
Fourwing saltbush				
Nuttal's Saltbush				
Rubber rabbitbrush				
Yellow sweet clover	Spring	0	1.1	3.98
	Fall	7.21	6.5	10.8
White prairie clover				
Greasewood	Spring			
	Fall			

Table B-12. Upton Site: Production Results

Production-grams/meter^2

Species	TREATMENT		
	Control	Furrowed	Gouged
Fairway	0	53.5	27.03
Thickspike	14.62	48.79	34.10
Nordan	46.03	80.52	44.66
Streambank	26.09	31.97	17.22
Western	15.24	20.07	31.74
Siberian	18.36	25.60	14.38
Pubescent	32.33	28.26	17.71
Buffalo grass		- not clipped -	
Canadian wildrye	13.97	16.21	20.47
Basin wildrye	0.60	7.12	3.45
Indian ricegrass	0	0.17	0.34
Squirreltail	0	6.59	19.19
Big sage		- shrubs were not clipped -	
Fourwing saltbush			
Shad scale			
Nuttall's saltbush			
Winter fat			
Rubber rabbitbrush			
Yellow sweet clover			
White prairie clover			
Greasewood			

Table B-13. Upton Site: Canopy Cover Results

Species	Control	Furrowed	Gouged
	TREATMENT	Canopy Cover in Percent	
Fairway	5.63	34.0	35.25
Thickspike	26.25	29.0	20.00
Nordan	26.50	40.0	25.00
Streambank	19.38	28.13	18.75
Western	20.00	16.88	23.13
Siberian	0	13.13	18.00
Pubescent	21.88	14.50	17.50
Buffalo grass	3.75	10.00	5.00
Canadian wildrye	21.25	15.00	23.33
Basin wildrye	4.13	5.25	2.05
Indian ricegrass	0	1.50	1.80
Squirreltail	0	0	30.00
Big sage	0	0	0.44
Fourwing saltbush	10.63	14.38	6.88
Shadescale	0	0	0
Nuttall's saltbush	2.00	0	0.63
Winter fat	0	0	0
Rubber rabbitbrush	0	0	0
Yellow sweet clover	42.50	2.75	1.75
Greasewood	9.50	13.13	18.25

Table B-14. Upton Site: Density Results

TREATMENT Species	Density-stems/meter^2 Control	 Furrowed	 Gouged
Fairway	14.85	102.37	82.13
Thickspike	79.55	140.04	108.18
Nordan	85.58	143.81	97.95
Streambank	101.29	171.15	129.71
Western	48.76	63.29	85.25
Siberian	55.76	51.45	45.43
Pubescent	60.82	56.62	42.95
Buffalo grass	4.63	1.61	0.22
Canadian wildrye	27.23	21.64	30.14
Basin wildrye	5.71	10.01	4.41
Indian ricegrass	0	6.14	9.04
Squirreltail	0	0	108.18
Big sage	0	0	0.16
Fourwing saltbush	0.97	1.29	1.29
Shadescale	0	0	0
Nuttall's saltbush	0.22	0.10	0.11
Winter fat	0	0	0
Rubber rabbitbrush	0	0	0
Yellow sweet clover	6.74	2.69	5.92
White prairie clover	1.40	2.58	0.75
Greasewood	1.94	1.72	2.58

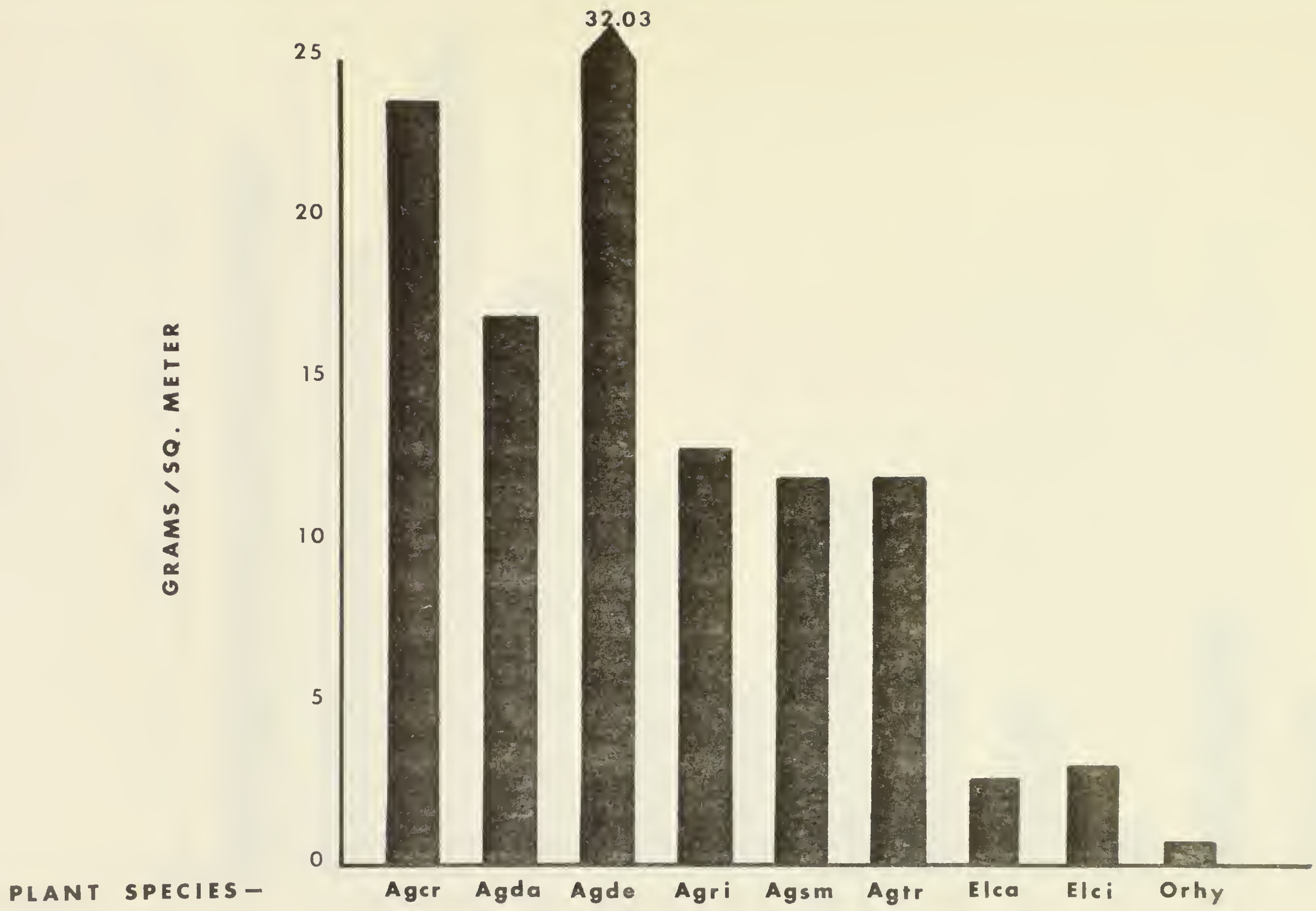

FIGURE B-7. INDIVIDUAL SPECIES: SUMMARY OF PRODUCTION RESULTS

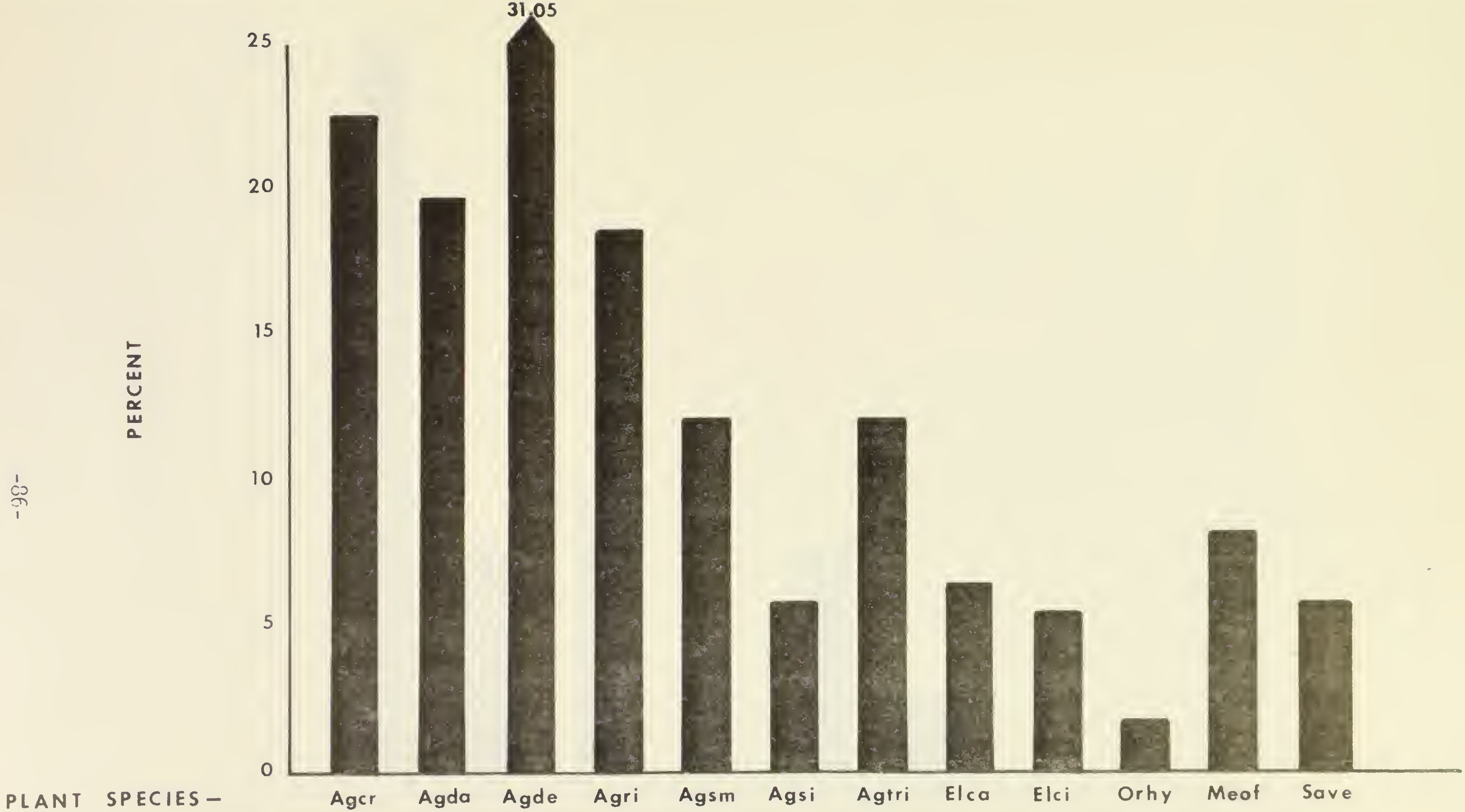

FIGURE B-8. INDIVIDUAL SPECIES: SUMMARY OF CANOPY COVER RESULTS

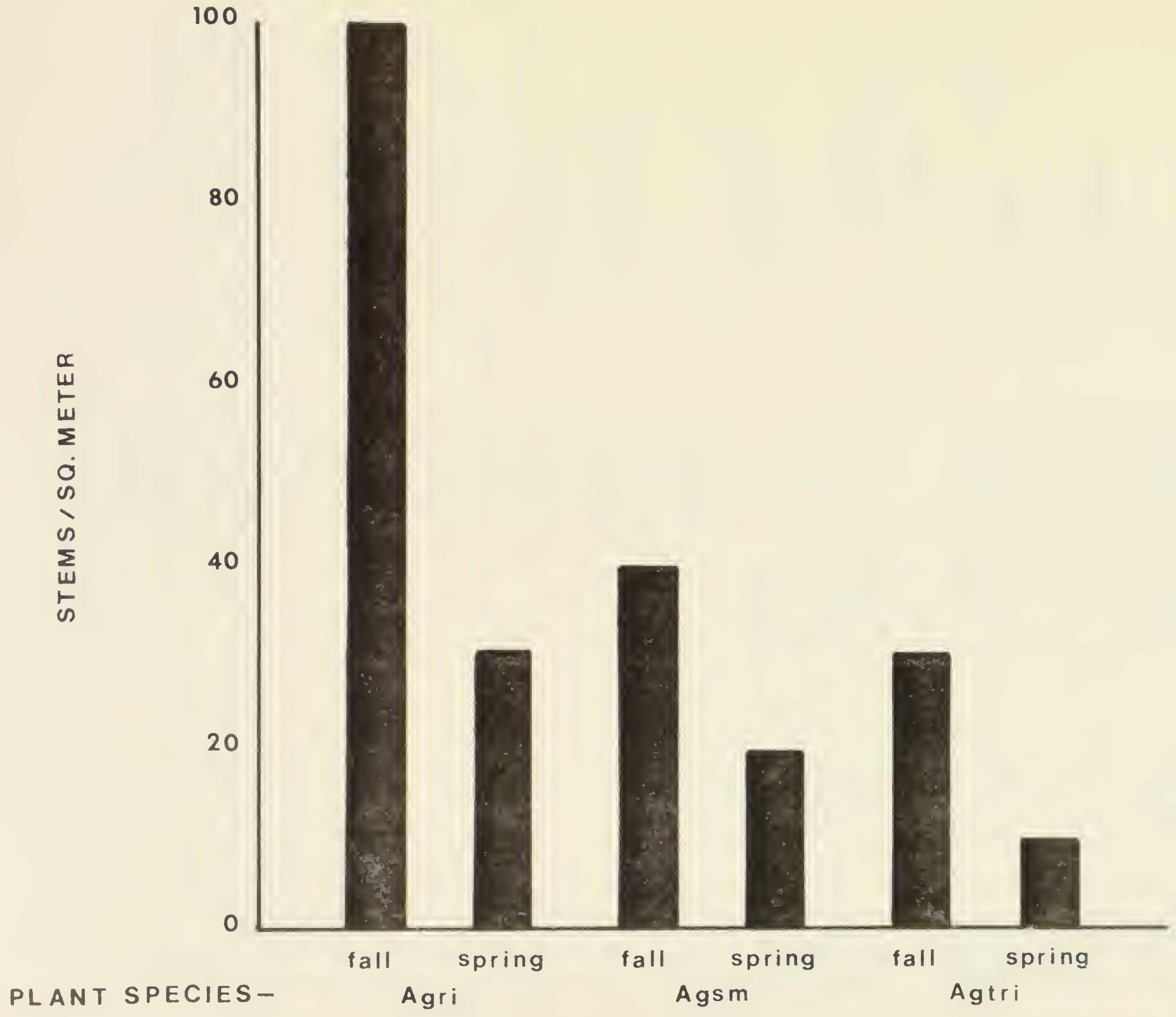

FIGURE B-9. INDIVIDUAL SPECIES: SUMMARY OF DENSITY RESULTS

Table B-15. Fertilization: Production Results

		Production-grams/meter^2		
FERTILIZATION RATE		150#/acre	100#/acre	0
Fairway crested wheatgrass		20.74	66.56	47.66
Thickspike wheatgrass	Spring	1.77	3.84	1.41
	Fall	4.94	23.36	21.81
Nordan crested wheatgrass		34.92	84.62	42.79
Streambank wheatgrass	Spring	2.24	2.92	2.13
	Fall	17.42	11.49	34.21
Western wheatgrass	Spring	0.64	1.26	1.08
	Fall	9.58	5.99	25.8
Siberian wheatgrass	Spring	0	0	0
	Fall	0	0	0.83
Pubescent wheatgrass	Spring	0.52	0	1.22
	Fall	24.2	19.4	24.25
Buffalo grass		-	-	-
Basin wildrye	Spring	0.64	0.09	0.02
	Fall	8.31	7.22	8.24
Indian ricegrass		0.63	0.26	4.28
Big sage	Spring			
	Fall			
Fourwing saltbush	Spring			
	Fall			
Nuttalls saltbush	Spring			
	Fall			
Rubber rabbitbrush	Spring			
	Fall			
Yellow sweet clover	Spring			
	Fall			
White prairie clover	Spring			
	Fall			
Greasewood	Spring			
	Fall			

Table B-16. Fertilization: Canopy Cover Results

		Canopy Cover in percent		
FERTILIZATION RATE		150#/acre	100#/acre	0
Fairway crested wheatgrass		50.0	51.5	41.67
Thickspike wheatgrass	Spring	1.83	10.88	5.78
	Fall	14.17	28.75	24.0
Nordan crested wheatgrass		41.67	55.0	37.78
Streambank wheatgrass	Spring	17.33	9.0	6.39
	Fall	25.0	20.0	33.33
Western wheatgrass	Spring	2.0	2.0	1.44
	Fall	6.67	10.0	18.33
Siberian wheatgrass	Spring			
	Fall			
Pubescent wheatgrass	Spring	.83	.50	4.06
	Fall	14.17	22.5	24.67
Buffalo grass				
Canadian wildrye				
Basin wildrye	Spring	.17	.50	.11
	Fall	7.0	5.63	13.06
Indian ricegrass		1.0	.88	4.28
Big sage	Spring			
	Fall			
Fourwing saltbush	Spring			
	Fall			
Nuttalls saltbush	Spring			
	Fall			
Rubber rabbitbrush	Spring			
	Fall			
Yellow sweet clover	Spring			
	Fall			
White prairie clover	Spring			
	Fall			
Greasewood	Spring			0.11
	Fall		2.5	0.55

Table B-17. Fertilization: Density Results

		Density- Stems/meter^2		
FERTILIZATION RATE		150$^\#$/acre	100$^\#$/acre	0
Fairway crested wheatgrass		238.86	219.16	152.10
Thickspike wheatgrass	Spring	27.88	36.17	18.84
	Fall	50.48	67.38	110.01
Nordan crested wheatgrass		100.43	171.15	124.43
Streambank wheatgrass	Spring	33.26	25.62	37.03
	Fall	134.88	103.24	167.06
Western wheatgrass	Spring	11.63	14.53	9.26
	Fall	47.04	29.71	93.54
Siberian wheatgrass	Spring			
	Fall			
Pubescent wheatgrass	Spring	3.55	1.08	10.44
	Fall	54.57	25.4	73.41
Buffalo grass				
Canadian wildrye				
Basin wildrye	Spring	1.40	1.40	0.43
	Fall	24.65	23.9	36.81
Indian ricegrass		5.17	3.23	19.59
Big sage	Spring			
	Fall			
Fourwing saltbush	Spring			
	Fall			
Nuttalls saltbush	Spring			
	Fall			
Rubber rabbitbrush	Spring			
	Fall			
Yellow sweetclover	Spring			
	Fall			
White prairie clover	Spring			
	Fall			
Greasewood	Spring			.11
	Fall		2.91	1.29

Table B-18. Summary of Season of Seeding Results

Spring vs Fall Seedings

	Canopy Cover in Percent		Density Stems/meter^2		Production grams/meter^2	
Colony	Fall	Spring	Fall	Spring	Fall	Spring
Pubescent wheatgrass	25.16	5.71	51.88	11.30	20.32	12.06
Western wheatgrass	19.41	6.71	80.41	24.97	15.79	5.18
Streambank wheatgrass	31.09	10.42	141.55	38.75	12.88	8.03
Alzada						
Pubescent wheatgrass	2.85	.92	5.23	2.15	0.76	1.09
Western wheatgrass	5.52	3.96	12.16	11.95	3.67	8.90
Streambank wheatgrass	9.58	3.17	19.38	9.15	8.03	2.16
Glasgow						
Pubescent wheatgrass	22.64	3.83	33.40	17.50	18.58	1.96
Western wheatgrass	28.73	7.76	28.70	23.00	14.67	4.71
Streambank wheatgrass	45.41	10.75	139.30	46.20	19.47	4.40
Colony Fertilized						
Pubescent wheatgrass	22.16	2.56	57.87	6.8	8.47	0.27
Western wheatgrass	14.06	1.69	68.86	11.02	7.03	0.37
Streambank wheatgrass	28.44	9.09	145.09	33.47	8.57	1.09

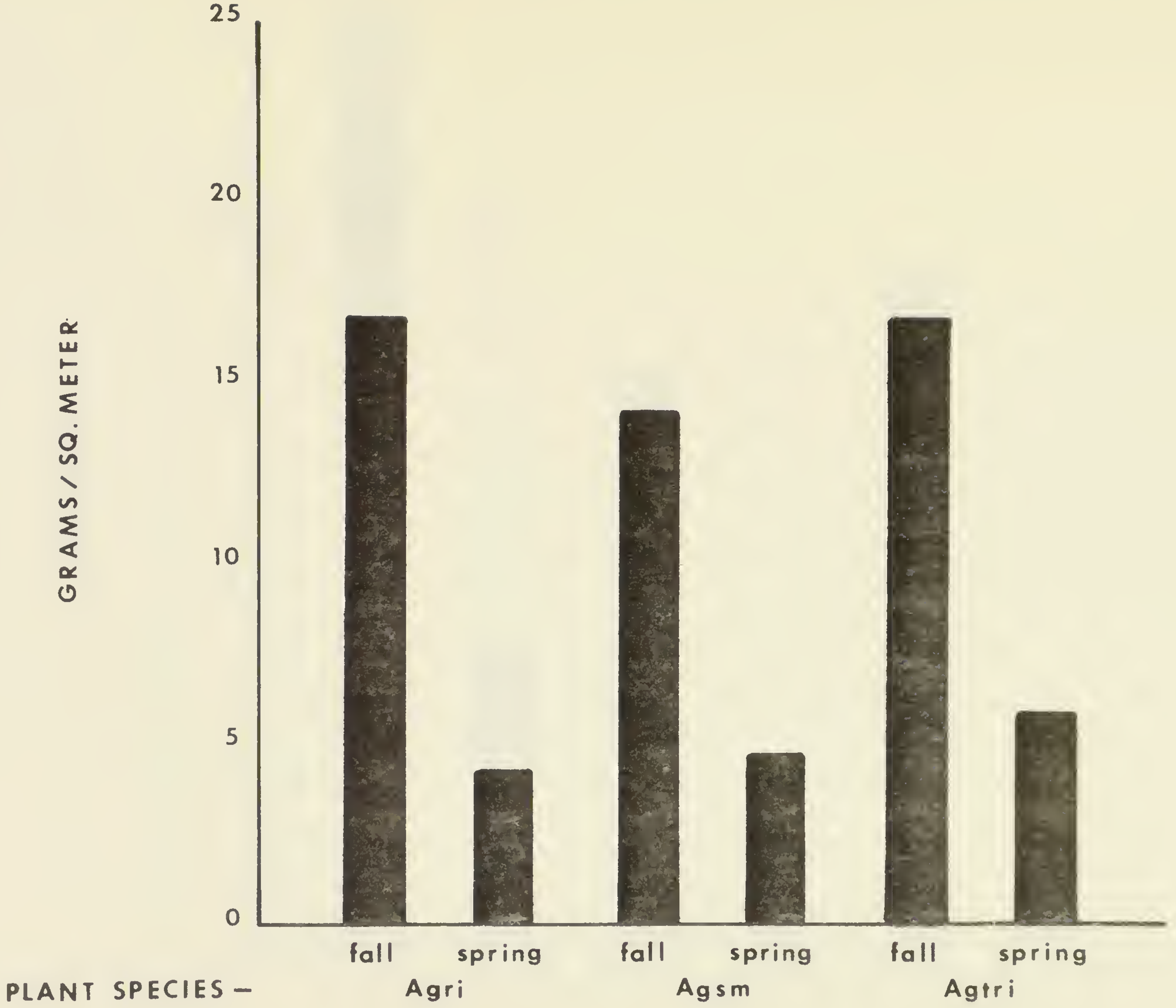

FIGURE B-10. SEASON OF SEEDING: SUMMARY OF PRODUCTION RESULTS

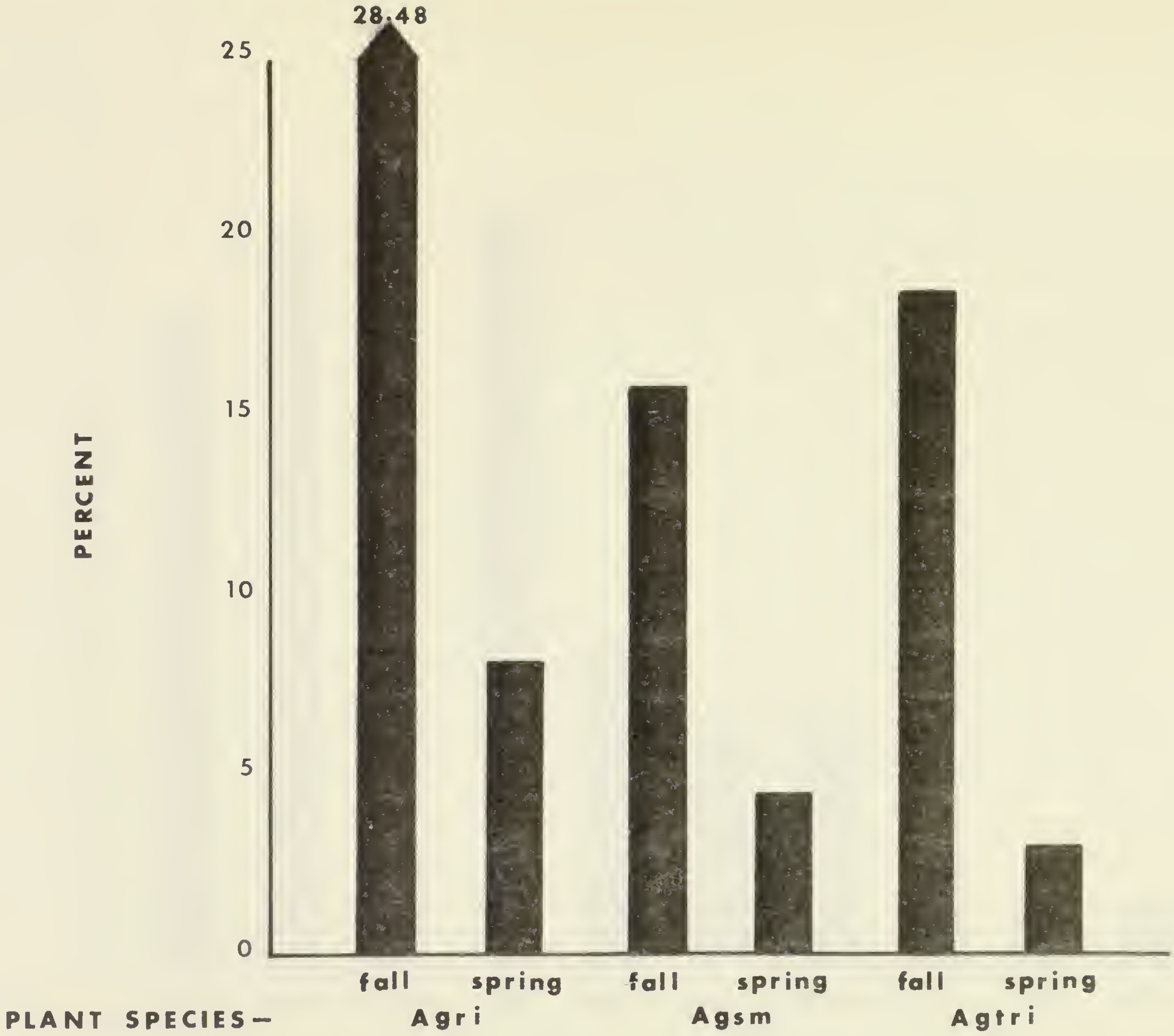

FIGURE B-11. SEASON OF SEEDING: SUMMARY OF CANOPY COVER RESULTS

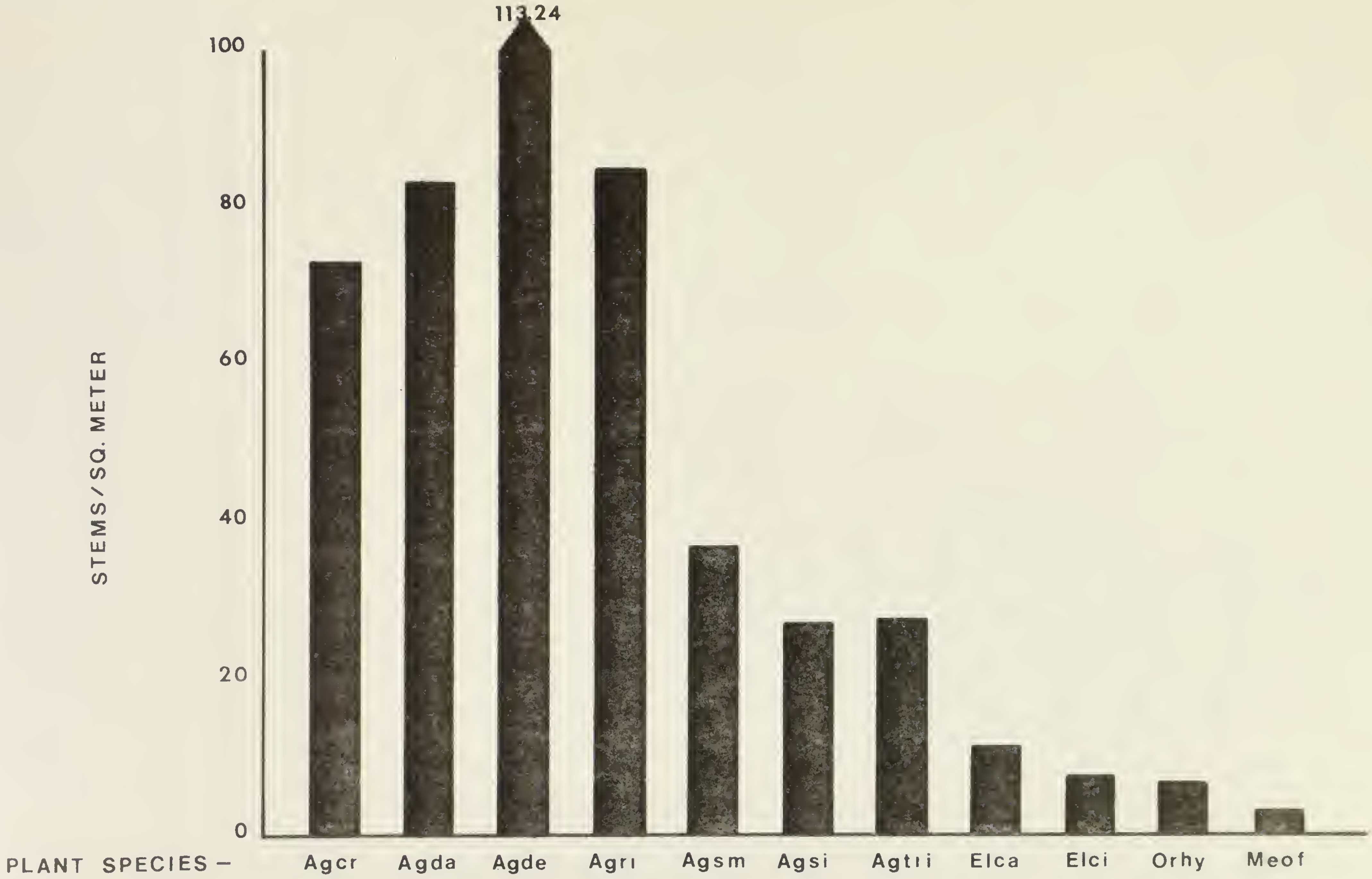

FIGURE B-12. SEASON OF SEEDING: SUMMARY OF DENSITY RESULTS